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ENERGY RECOVERY FROM SOLID WASTE

Volume 2 - Technical Report

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16. Abstract

A systems analysis of energy recovery from solid waste demonstrates the feasibility of several current processes for converting solid waste to an energy form. The problem is considered from a broad point of view. The social, legal, environmental, and political factors are considered in depth with recommendations made in regard to new legislation and policy. Biodegradation and thermal decomposition are the two areas of disposal that are considered with emphasis on thermal decomposition. A technical and economic evaluation of a number of available and developing energy-recovery processes is given. Based on present technical capabilities, use of prepared solid waste as a fuel supplemental to coal seems to be the most economic process by which to recover energy from solid waste. Markets are considered in detail with suggestions given for improving market conditions and for developing market stability. A decision procedure is given to aid a community in deciding on its options in dealing with solid waste. A new pyrolysis process is suggested. An application of the methods of this study are applied to Houston, Texas.

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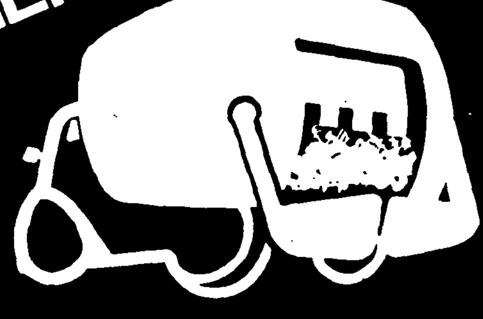


1.1 THE SOLID WASTE PROBLEM

It is estimated that the amount of solid waste generated daily in this country averages between 1.18 and 1.81 kilograms (2.6 to 4 pounds) for each person. The exact estimate within this range depends on the authority quoted. Even at the lower estimate, the total mass of material to be handled is overwhelming and the average per person, as well as the total, is increasing. The material comes from many sources and with a great diversity of physical form and chemical composition.

Contributing to the problem is the fact that, concurrent with the steadily increasing mass of solid waste for disposal, traditional methods of disposal are becoming less and less acceptable socially and environmentally, or economically, practical. The reasons are many and include a complex interaction of political, environmental, legal, social, economic, and technical considerations.

Disposal of solid waste is one of the most difficult and frustrating problems facing municipal authorities.

1.2 WHY ENERGY AND RESOURCE RECOVERY FROM SOLID WASTE?

For many decades our concern with solid waste has concentrated on disposal. The attitude has been: Get rid of it--somehow, somewhere. Only recently have we begun to focus attention on its utilization. A growing awareness is developing that we as a nation are consuming our nonrenewable metal, mineral, and energy resources at a rate faster than population growth. A logical result of this awareness is the realization that solid waste is in itself a resource; we are discarding via the garbage can a high proportion of our primary resources.

The combination of the growing unacceptability of traditional disposal methods along with the need to conserve the nation's resources has spurred efforts to exploit solid waste. Initially, efforts were concerned with recovering materials; ferrous and nonferrous metals, glass, and paper. The current energy shortage helped stimulate a further awareness that the high percentage of organic material including solid paper in solid waste represents an energy resource. More recent utilization efforts, therefore, have included the development of ways to recover effectively the energy resources inherent in solid waste.

Although it makes good sense to recover energy and materials from solid waste, many problems remain to be solved before such recovery can be practiced widely, efficiently, and economically. The investigation in this report is an attempt to help solve some of these problems.

1.3 PARAMETERS OF THE STUDY

Emphasis in this study is primarily on energy recovery from solid waste. However, it is virtually impossible to consider energy recovery techniques without also considering the recovery of materials. In many instances, both types of recovery will be necessary for an economically viable process. In general, however, resource recovery is given somewhat less emphasis in this study.

The collection of solid waste is considered to be outside the scope of this study and is not treated in any detail. There are several reasons for this. First, much excellent work already has been done on the collection problem. Second, the need for collection is not unique to energy and resource recovery; it still must be done for traditional disposal practices, and collection methods will not differ too much in either case. Third, as a nationwide average, the collection of solid waste costs about $45 per ton and represents about 80 percent of the total for present traditional disposal costs. However, current trends in disposal costs are such that collection undoubtedly will present a much smaller proportion of total solid waste handling costs in the future. The design group concluded, therefore, that it was best to restrict the study efforts to the recovery technologies.

Solid waste, as treated in this study, consists of what generally is known as Mixed Municipal Refuse (MMR). It is what the municipality normally picks up at the curb of residences and from commercial and institutional buildings.

Sewage treatment and the handling of industrial wastes are specifically excluded from this study.

1.4 THE APPROACH FOLLOWED

In carrying out the study, we have attempted first to identify the various nontechnical aspects of the solid waste problem: political, environmental, legal, social, and economic. Solutions are suggested for at least some of these problems. It is recognized that the dividing line between nontechnical and technical problems sometimes is vague, and we have attempted to show the interactions between the two.

Insofar as possible, we have tried to identify all of the publicly known techniques or processes for recovering energy or materials from solid waste. At least 30 processes exist for the conversion and recovery of energy products and these can be categorized broadly as incineration, pyrolysis, or biodegradation processes. Numerous variations are possible within each broad category.

Energy products may be in the form of solids, liquids, or gases -- or energy may be recovered more directly as hot water or steam. Some processes recover combinations of these several types of energy. The form, or forms, of energy and other products recovered depend on the type of process, its operating conditions, and economic factors.

All levels of technical development are represented by the many different processes available. Some are still in the R & D stage and some are in pilot plant testing. In some instances commercial-scale facilities are under construction, and several commercial-scale units are completed and in operation.

These various levels of development and the different capacities involved make comparative evaluations difficult. However, we have attempted to compare the technical and economic characteristics of the different processes -- including their social, environmental, and related considerations -- on as nearly an equitable basis as possible. Where data do not exist or are proprietary, we have exercised our best engineering judgment when making estimates.

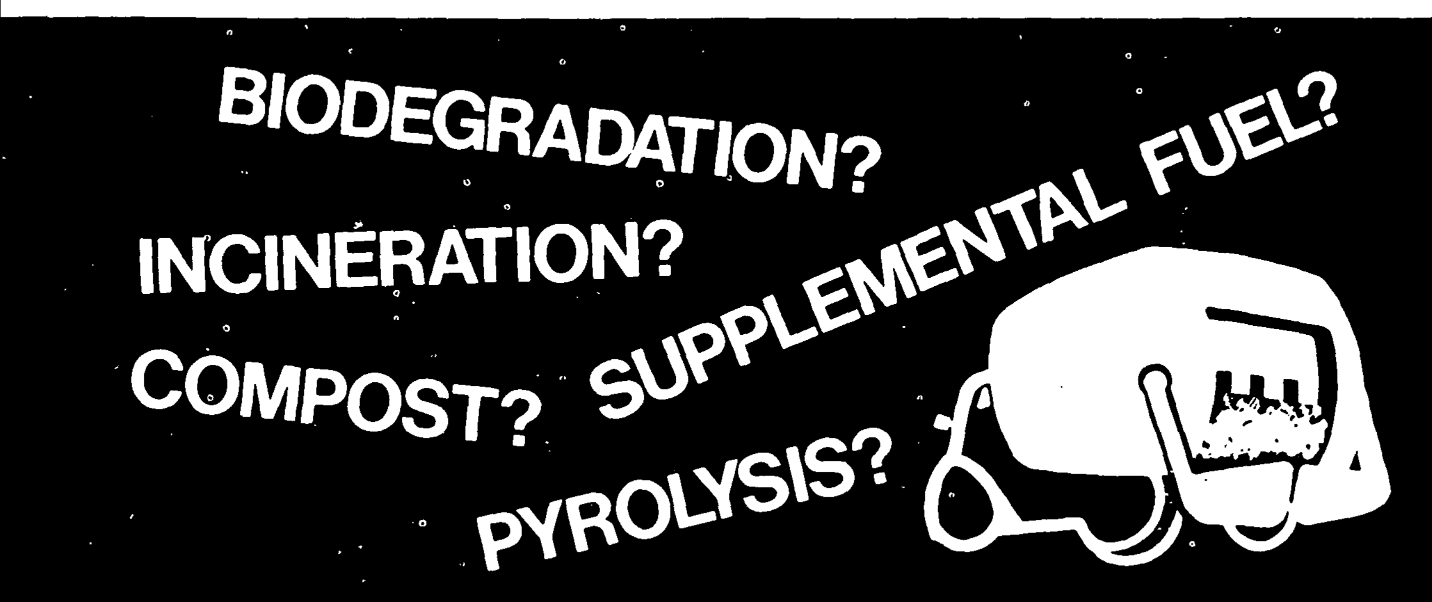
Along with this activity, a concept for a new pyrolysis process was developed and is suggested for further research.

Various aspects of the marketing situation and other utilization factors relating to the different energy and recovered products are analyzed and discussed.

As the study progressed, it became evident that no single conversion process was superior to all others as an answer to the solid waste problem under all condition The choice of appropriate conversion proces for energy resource recovery is highly sensitive to the local situation. The study group therefore developed, and describes in this report, a decision model employing the systems approach. It believes that this model will be helpful to municipal authorities in selecting from among the many alternatives available the best route to follow -- energy recovery, materials recovery, or both -- and the conversion process best suited to their particular local situations.

Chapter 2
Social Aspects of Solid Waste Management

ENERGY RECOVERY FROM SOLID WASTE



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2-1 INTRODUCTION

Louie Welch, former mayor of Houston, Texas, once said "Everyone wants us to pick up his garbage, but no one wants us to put it down". This sentence succinctly summarizes the solid waste problem facing American cities. In a climate of public opinion which is frequently hostile, and at best apathetic, municipal governments must cope with the dual problem of solid waste collection and disposal. The average citizen is primarily concerned with collection. He is unconcerned with disposal unless the disposal site is near his home. This leaves the city officials with the near impossible task of finding an acceptable disposal method.

A recent survey (ref. 2-1) by the National League of Cities (NLC) emphasizes this lack of concern on the part of citizens and the ambivalent attitudes of municipal officials. The survey found that both mayors and city councilmen ranked refuse and solid waste as the most important of 28 major urban problems. However, when these problems were grouped into 8 substantive categories, environmental concerns (which includes solid waste management) ranked 5th. Thus, solid waste management as a general priority is not high on the average municipal agenda. The NLC survey also attempted to gauge the perceptions of municipal officials about citizen priorities by asking officials the question, "What do citizens frequently complain about?" The 14 different problems mentioned ranged from dog and other pet control problems (most frequently mentioned) to fire protection (least frequently mentioned), but solid waste was not even named as an area of citizen concern.

The primary reason why solid waste has become such a large problem for most cities is that Americans are generating more and more garbage each year. At the present time each person in the U. S. generates about 1.18 kilograms (2.6 pounds) of solid waste per day. While Americans are producing more and more solid waste, constraints are being placed upon disposal methods.

In the past, open dumping and burning was the method of disposal used by most communities. However, regulations restricting air and water pollution have led to the closing of many open dumps. Sanitary landfill and incineration have become the two environmentally acceptable waste disposal methods. Two points must be considered with respect to landfills and incineration. First, most of the municipal solid waste in the United States is disposed of in open dumps. Over 80 percent of municipal refuse is simply dumped. Approximately 8 percent is incinerated, and only 6 percent is put in sanitary landfill (ref. 2-2). Second, many sanitary landfills and over 70 percent of incinerators have had pollution problems (refs. 2-2, 2-3). Thus, the use of sanitary landfill or incineration does not necessarily mean that refuse is disposed of in an environmentally sound manner.

The responsibility for refuse collection and disposal generally rests with the municipality, although counties often have responsibility for unincorporated areas. In some instances, states have disposal responsibility (Connecticut, Vermont, Wisconsin); or the responsibility lies with a regional authority.

Cities must change the way in which they dispose of Mixed Municipal Refuse (MMR). A disposal system must be "economical" and not pollute air or water, but most of all it must be a method of disposal which does not create political difficulties.

There has been much discussion on utilizing the energy content of MMR and on recovering potentially useful materials from refuse. But trash disposal is low on the agenda of both decision-makers and the general public. The public usually does not have much knowledge about public policy issues, nor is the average person interested in public policy. The problem of solid waste disposal is no exception. Those data which are available indicate the perception by municipal officials to be correct; solid waste is of little concern to the general public. An Illinois survey found over 70 percent of that state's residents to be satisfied with present collection and disposal methods. To the extent that respondents perceived problems, they dealt exclusively with collection, e.g., noise, bent or damaged trash cans, and odor (ref. 2-4).

A national sample of American housewives found that a third of those interviewed were unaware of what happened to their trash once it was removed from their premises. Over two thirds of those interviewed reported never having considered the costs of solid waste collection and disposal prior to the interview (ref. 2-5).

For a number of reasons, the solid waste concerns of public officials are also primarily in the area of collection:

1. Most of the cost of solid waste management (over 80 percent) is in collection. Currently, less than 20 percent of a city's solid waste management budget is for disposal, although this proportion can be expected to increase sharply as existing landfills are exhausted.

2. For health, aesthetic, and political reasons, garbage must be collected on a regular basis without interruption. The decision-maker is concerned with scheduling, dispatching, and system reliability in

collection services. Just getting the men and trucks out and the insuring that the garbage is collected occupies most of the energies of municipal solid waste officials.

3. The mass public is primarily concerned with collection. Almost all of the contacts between the public and municipal solid waste managers involve collection problems. A public official who is responsive to his constituency finds himself responding primarily to collection difficulties. The only interest the mass public has in disposal is making sure that disposal (primarily landfill) does not take place in his neighborhood.

4. The preoccupation of both public officials and the mass public with the day-to-day problems of collection is one reason why so little effort goes into innovations in disposal or in long range planning.

Additional factors tending to discourage planning and innovation are uncertainty about:

1. System cost: The Houston Texas, Holmes Road incinerator cost over $6 million and was shut down after only a few years of operation because of frequent equipment and air pollution problems. The cost of disposal at the facility during its final year of operation was about $29 per metric ton ($26 per ton) in operating costs alone.

2. System reliability: Garbage is collected regularly, and must be dealt with on a continuing basis. Many innovative disposal systems have been proposed (e.g. pyrolysis, anaerobic digestion, resource recovery, etc.) but they are yet of unknown reliability. The fact that MMR must be disposed of continually puts a political premium on system reliability. A city cannot suspend garbage services for a few days or weeks while repairs are effected on some exotic new disposal system.

3. Public acceptance: Long range planning and innovation depends on public cooperation. The location of future disposal sites is an important aspect of long range planning. However, the selection of disposal sites is inherently a political process. Planners may choose a disposal site on a number of important criteria, e.g. geological suitability or geographic proximity. But if a landfill site cannot be used because of political pressure from neighborhood residents, then such planning is useless. Neighborhood opposition can often be reduced by making commitments for future park and recreational utilization of completed landfills, but this must be done on an ad hoc basis at the time a new disposal site is brought into service.

Innovative disposal systems are also subject to the vagaries of public acceptance. The city of Houston was forced to abandon a large resource recovery and compost system because of the opposition of nearby residents who complained about odor, litter, and traffic problems. When residents began lying down at the facility entrance to bar the admittance of compactor trucks, the city was forced to close the plant after only 6 weeks of operation. The closing resulted in a $2½ million loss by the City to the company which had contracted with the City to build and operate the facility.

2.2 FACTORS DETERRING CHANGE

2.2.1 Cost

The collection and disposal of municipal refuse is a regular and constant responsibility. Furthermore, it is a responsibility ordinarily assumed by local governments, and as such is the object of public interest and scrutiny with respect to the cost of collection and disposal service. Public opinion generally favors the least expensive acceptable mode of municipal service provision. The political problem facing cities is deciding which method of disposal is publicly acceptable. However, as will be discussed later, reliably estimating the costs of alternative disposal systems is also something of a problem.

Aesthetic, public health, and environmental considerations have resulted in the banning of open dumping. Although inexpensive, open dumping is unacceptable. Gradually, communities are being brought into compliance, switching from open dumps to landfills or incineration. These latter two disposal methods are more expensive than open dumping, but do not have the social and environmental liabilities of dumping. The costs of landfill and incineration are rising in most areas as landfills must be located in more remote locations and as existing incinerators must be modified to meet current air quality standards. In spite of this, landfill is generally less expensive in most locales than any other acceptable disposal system.

Many new disposal systems have been proposed which would incorporate energy and resource recovery from municipal refuse. However, there are no "hard" cost estimates for these processes, and experts often disagree as to probable costs. Those cost data which are available indicate that, in general, new disposal technology will be more expensive than landfill or incineration without energy recovery. Most communities will resist conversion to new disposal systems, and will continue to landfill or incinerate until the new technologies have more favorable proven cost and operating reliability. However, it should be kept in mind that disposal system costs are <u>extremely</u> location dependent. A community which has high landfill costs, high energy costs, and good local markets for secondary resources may find a new disposal system (e.g. resource recovery and pyrolysis) to be the least expensive alternative. This can only be determined by a careful analysis of the needs and resources of each individual community. In general, however, until the economic superiority of a new disposal system can be clearly demonstrated, decision makers will have little choice but to continue existing disposal practices.

2.2.2 Maintenance of Political Stability

Politics is the authoritative allocation of valuables. Political decisions are generally evaluated in terms of the marginal advantages and costs to the members of the political system. For that reason any change in an existing policy changes the distribution of costs and benefits, disrupts the political equilibrium of the status quo, and awakens an otherwise disinterested public. This is particularly true of policies which affect people's everyday life. Thus, decisions on foreign aid may arouse little public interest, while a municipal decision to change solid waste collection practices by introducing source separation of cans and paper may generate a great public interest and commentary. Local governments are routinely involved in a myriad of potentially disruptive decisions. To the greatest extent possible, local officials will attempt to avoid decisions which may arouse political opposition by creating a new group of marginally disadvantaged citizens. Except in a crisis situation, it is politically perilous for municipal officials to substantially change existing solid waste practices, and few changes should be expected. The fact that improved solid waste management is not of major concern to either city officials or the public also helps maintain the status quo.

2.2.3 Industrial Interest Groups

A number of industrial companies specialize in solid-waste collection and disposal, and many municipalities contract with private companies for solid-waste services. These contracts are often for periods of several years or longer to allow for manpower and capital planning. Existing contractual obligations will constrain municipalities and impede changes in solid waste management practices.

The industrial organization of many sectors of the economy also is a factor impeding changes in current solid-waste practices. The paper industry is a good example. Vertical integration in that industry has led to the domination of the industry by a small number of firms who handle every aspect of production from the growing of trees through the final fabrication of finished paper products. Because of this, pulp and paper mills tend to be located near the areas where trees are grown. A change in solid-waste practices such as the source separation and recycling of paper is impeded by that pattern of capital investment because paper and pulp mills are somewhat distant from the urban areas which would be the main source of recycled paper.

We must also consider the lobbying effort of many industries. As is discussed in another portion of this report, current practices are motivated by such political decisions as depletion allowances, capital gains tax provisions, differential transportation rates, etc. Representatives of various industries may lobby against change in order to preserve existing patterns of industrial organization and investment. For example, it is not implausible to expect the Glass Container Manufacturers Institute to oppose national deposit container legislation which would shift beverages from disposable glass containers to deposit bottles.

2.3 ENVIRONMENTAL AND OTHER FACTORS MOTIVATING CHANGE

In recent decades, man has begun to recognize the profound effect his activities have on the entire earth-air-water system. It has become increasingly clear that some of these environmental changes would be irreversible and detrimental to public health if immediate preventative measures were not taken. Although general environmental deterioration was a concern, the underlying rationale of most Federal environmental legislation has been the protection of human health.

The most obvious and easily regulated dangers to public health are air and water pollutants. Legislative traditions in the United States provide few precedents for this kind of government regulation. In most parts of the country in the past, individual rights to air and water (except for the purpose of navigation) had been closely associated with the ownership of land. This situation gradually changed as the knowledge of the relationship between pollutants and health increased and as public awareness of environmental problems grew. Because improper disposal of solid waste pollutes air and water, environmental legislation regulating pollution has reduced the number of acceptable disposal options. The banning of environmentally undesirable disposal practices and the increasing usage of petroleum and other nonrenewable resources has increased interest in new disposal systems which recover energy and other resources from municipal solid waste.

2.3.1 LAND DUMPING

The time-honored method of disposing of municipal solid waste was simply to haul it a short distance from town and dump it on the ground. There it may have remained in the open air, or it may have been burned, or mixed with soil in a landfill. Current waste-disposal practices are not much different; about 80 percent of all municipal refuse is still put into the ground. This method always presents the potential of pollution to both air and water. However, carefully planned and managed landfill sites can significantly reduce this potential hazard (ref. 2-3).

The two methods of land disposal in common use are open dumps and sanitary landfills. Open dumps pose many pollution problems and deserve the name "environmental insult" which has frequently been applied. Trash in open dumps is usually burned, either accidentally or intentionally. In any case, the burning contributes to air pollution and frequently violates Federal and local air quality standards. Open dumps provide a perfect home and breeding place for disease-carrying animal and insect pests (ref. 2-6). Examples of at least 22 human diseases, including hepatitis, have been linked to improper waste-disposal methods (ref. 2-7).

Production of methane gas through the decomposition of organic waste is an additional hazard, particularly if the gas is allowed to accumulate. More recently, the possible commercial exploitation of methane from landfills may turn this liability into an asset (see discussion elsewhere in this report on the NRG NuFUEL Company methane recovery program) (ref. 2-8).

Surface water can be directly polluted by runoff from open dumps of organic and inorganic material. If the bottom of the dump extends below the local groundwater table, internal leachate can also pollute subsurface water (ref. 2-9). Odor and wind-blown paper from open dumps are more of a nuisance than a serious pollution problem. However, these latter may be a major concern to residents of the surrounding area.

If open dumps are so undesirable, why then do they continue to be the single most common important method for disposal of municipal solid waste? Land disposal, per se, is not regulated in most parts of the United States. Where regulations do exist they are frequently not strongly enforced (ref. 2-10). In most areas, however, open dumps are directly or indirectly illegal because of air and water pollution regulations as well as local sanitation laws (ref. 2-11). In spite of this, offending open dumps cannot be closed in some cases because no other economically or politically acceptable alternative exist. Although open dumps are not directly affected by Federal regulations, the EPA has vigorously supported efforts to establish land-disposal regulations on the state, county, and municipal level. Mission 5000, a Federally sponsored publicity campaign of the late 1960's, had as a goal the closure of 5000 open dumps. The drive had some success, and open dumps have become more socially unacceptable. However, without uniformly strong land-disposal regulations backed by enforcement, open dumps will be difficult to eliminate completely because they are the cheapest disposal method.

Sanitary landfills represent an improvement over open dumps, although plagued by the same potential hazards as open dumps. However, if site selection, based on geologic and hydrologic criteria, is coupled with sound engineering practices, pollution may be kept to a minimum (ref. 2-3). In a sanitary landfill, waste is spread in thin layers and compacted and covered with a layer of soil. This process is repeated as many times as the area to be filled permits. Although the operation of any landfill will be influenced to some extent by the quantity and composition of refuse to be filled, an earth cover of at least 15.2 centimeters (6 inches) of compacted soil should be provided at the end of each day of operation. This cover will aid in rodent and insect control as well as help eliminate odor and blowing refuse. Unfortunately, too many sanitary landfills are more cosmetic than sanitary.

For a landfill to be truly sanitary it must not pollute water supplies now or in the future. Pollution of surface water by runoff is relatively easy to control by proper design and by artificial drainage with leachate removal if necessary (ref. 2-3). Subsurface water pollution may be more difficult to control; frequently, it is not apparent from surface evidence (ref. 2-11). The pollution of subsurface waters by material landfilled in an improperly located site may not occur until many years in the future. A recent example of human poisoning in Minnesota in 1972 occurred after several people drank well water which had finally become contaminated by arsenic wastes buried 30 years before on nearby land (ref. 2-12).

In addition to proper site selection, a successful sanitary landfill needs continuous maintenance, including the monitoring of pollutant levels of leachate, even after the site is completely filled. Subsurface water pollution will result if landfill substrata are permeable and the groundwater table is low.

Leachate is produced within a landfill whenever water, from any source, reacts with refuse. All landfills produce some leachate (ref. 2-13). The composition and strength of the leachate will depend on a number of complex factors, including the composition of refuse in landfill, the amount of infiltrated water, and the length of time infiltrated waste is in contact with refuse. The pollution potential of a landfill depends on the mobility of contaminants and the accessibility of leachate to the groundwater reservoir. In part, pollution potential may be partially dependent on climate. Landfills in areas with high rainfall are more likely to pollute than those in dryer areas. In fact, landfills in very dry areas present almost no pollution hazard because all infiltrated water is either absorbed by refuse or is held as soil moisture which ultimately evaporates.

Leachate from landfills contains both organic and chemical contaminants. Organic material consists of suspended material and bacteria. Sandy and silty soils will retard the movement of organic material, and often filter them from percolating leachate (ref. 2-14). Chemical contaminants, because they are in solution, usually travel faster and further than biological contaminants. The major decomposition products of refuse are carbon dioxide and methane. Methane, since it is insoluble in water, does not contribute to water pollution. Much of the carbon dioxide may be dissolved in the water which has infiltrated the landfill. This resulting weak carbonic acid can then react with carbonates, sulfates, chlorides, and silicates present in both the refuse and enclosing soil and rock units. At best, this process of higher mineralization can lead to increased water hardness. At worst, this process may result in the introduction of toxic metal compounds into subsurface waters.

What harmful chemical materials are commonly found in municipal waste? There is always a possibility that small quantities of very hazardous exotic material will get into the municipal waste stream. Household chemicals for cleaning and gardening, pigments, and solvents are frequently toxic and found in small quantities in refuse. Toxic substances may also be produced during the bacterial degradation of food wastes, especially from meat and fish (ref. 2-15). Chemical and biochemical reactions within a landfill are complex and this is an area that requires more research. However, we do know that the decomposition of refuse is continually releasing intermediate products which are soluble and toxic, whereas the primary product was not. Organic activity can also increase the toxicity level of originally lethal material. For example, anaerobic bacteria can convert inorganic mercury into more toxic methyl mercury (ref. 2-12). Other materials generally considered safe can also present a pollution hazard. "Inert" incinerator residue is usually landfilled. This material consists of metal oxides incorporated in a vitreous frit (ref. 2-16). These metal oxides may be removed when they come in contact with acidic leachate in a landfill. However, it will take more time to leach this material than organic refuse.

Many existing landfill sites were selected because of low real estate values or political considerations rather than appropriate geological criteria. Improperly located sites will require remedial modification to comply with existing and future regulations. Ideally, the substrata of a landfill should have a low permeability and high water-holding capacity and should be as far from an aquifer as possible. Clay-rich substrata usually make very secure sites for sanitary landfills. In many areas, intense competition for land among agricultural producers, suburban developers, and other interests has driven up land prices and led to the utilization of abandoned sand and gravel pits for disposal sites. This method is less expensive since land values are usually lower and excavation costs are eliminated. Unfortunately, these sites are likely to pollute subsurface waters because of the high permeability of sands and because of the frequent direct communication of this type sandy substrata with local shallow aquifers.

The pollution problems associated with land disposal are severe and should lead us to discontinue the use of this method of waste disposal, except in certain limited instances. However, in high density population areas, more pragmatic reasons such as land shortages or excessive land costs may provide the motivation to explore new disposal methods. Landfilling consumes about 2 acres of land per year for each 10,000 people when the compacted refuse in the fill is 2.1 meters (7 feet) deep (ref. 2-14). At this rate, a city with a population of one million people will use 100 acres of landfill a year. This quantity of land is frequently just not available in areas surrounding the nations' larger cities. Or if land is available, it frequently has geologic and hydrologic parameters which make it unsuitable for land disposal.

2.3.2 Ocean Dumping

Ocean dumping has been used for many years as a disposal method for a wide variety of industrial, military, and municipal wastes (ref. 2-17). Although municipal waste made up the smallest amount of material that was ocean dumped, the total tonnage continued to grow in the late 1960's and early 1970's. Due to increased restrictions on air and fresh water pollution and because of scarcity of new landfill sites, cities found sea disposal increasingly more attractive for both economic and practical reasons. By 1971, a number of major seaboard cities (New York, San Francisco, Boston, and Philadelphia) had either initiated or had shown interest in various schemes for sea disposal of both loose and baled garbage. Disposal costs were cheap, averaging approximately $3.00 per ton (ref. 2-18), and in most areas regulations were not restrictive as long as disposal practices did not produce ocean or beach blight. In most cases, the overall effect of garbage to the marine environment and its biota was not considered.

Ocean dumping regulations were administered by a wide range of Federal, state, and local agencies with little or no attention given to long-range planning (ref. 2-18). Frequently, regulations were not comprehensive and little interagency coordination took place, resulting in overlapping duplication, and confusion. As a consequence, little reliable data exist today on the total amount and types of materials dumped in the oceans before 1972.

Widespread ocean dumping ceased with the passage of the Marine Protection, Research, and Sanctuaries Act of 1972. This law prohibits ocean dumping into the territorial waters of the United States of any agent of warfare (radioactive, chemical, or biological), high-level radioactive wastes, or any other material, except as authorized by Federal permit issued by the EPA or by the Corp of Engineers for dredged spoil. Before granting any permits for ocean dumping, the EPA must evaluate "appropriate locations and methods of disposal or recycling, including land-based alternatives, and the probable impact (of such use) upon considerations affecting the public interest". The prohibition on ocean dumping does not affect a large percentage of the nation's municipal solid waste. It does displace large volumes of industrial wastes for land-disposal sites, which in turn increases pressure for new technology in solid waste-disposal.

2.3.3 Regulations Relevant to Solid Waste

Increased post World War II production and consumption have resulted in an alarming growth in the nation's solid waste. In 1973 the United States Conference of Mayors of the National League of Cities (ref. 2-19) estimated that the volume of solid waste generated in cities had doubled in the preceeding 20 years. This increasing amount of solid waste has significantly contributed to air and water pollution as well as to general environmental deterioration.

Prior to 1960, there were few laws dealing specifically with the preservation of the environment (ref. 2-20). However, even then some of the nation's streams and lakes had become unfit for recreation and were unable to support many desirable forms of fish and plant life. Public awareness of pollution came first in the area of water and air pollution. One of the first environmental regulations was the Atomic Energy Act of 1954 which regulates the safe disposal and storage of radioactive wastes. In 1955, a study of air pollution was initiated at the Federal level by a $1 million appropriation to the Public Health Service. The following year, the Federal Water Pollution Control Act was passed authorizing a 5 year, $250 million dollar program to aid in the construction of municipal sewage treatment plants. These laws represent the only major pieces of environmental legislation of the 1950's.

Environmental legislation in the early 1960's continued to emphasize air and water pollution. In general, these laws were regulatory, although most of them also provided research and grant monies. In 1960, the Surgeon General began a study of air pollution by automobiles which resulted in 1968 in the first automobile emission standards.

In 1961, the Federal Water Pollution Control Act was extensively amended; enforcement was placed under the direction of the Surgeon General. Funding was increased to $100 million dollars a year and regulations extended to include navigable as well as interstate waters. The emphasis on pollutant-free air was continued by the passage of the Clean Air Act of 1963. This law provided the first federal abatement procedure in cases of interstate air pollution, and provided additional money for research and technical assistance. The Clean Air Act of 1965 revamped and expanded the air quality programs and established additional emission standards. In 1966 and 1967 the Clean Air Act was again amended and its funding for research and grant programs was greatly expanded. The 1967 amendments are of particular importance because they provided air quality control criteria, air quality control regions, and a mechanism for Federal action if states failed to act.

A major piece of water pollution legislation, The Water Quality Act, was also passed in 1965. This act created the Federal Water Pollution Control Administration and placed its administration under the Department of Interior. Most important, the act authorized mandatory standards for interstate water quality. The Clean Water Restoration Act of 1966 authorized a massive increase in Federal funds to clean up the nation's waters. The bill provided money for the study of estuary systems and it removed funding ceilings for communities seeking aid in bringing water supplies up to Federal standards.

Near the end of 1969, Congress enacted the National Environmental Policy Act (NEPA) which created the Council on Environmental Quality, a three-man executive advisory board appointed by the president. The Council was charged with responsibilities in four areas: 1) determining the condition of the country's environment, 2) developing new environmental policies and programs, 3) coordinating all Federal environmental programs between various agencies, and 4) insuring that all activities of the Federal government take environmental considerations into account. The performance of this last function of the Council was assured by regulations requiring all Federal agencies to prepare detailed environmental impact statements on "proposals for legislation and other major Federal actions significantly affecting the quality of the human environment", if deemed appropriate by the EPA. This requirement also applied to Federally funded demonstration projects and to contractors of the Federal government. If the EPA's preliminary determination was that the proposed action was neither "highly controversial" or had no "significant environments effects", a "negative declaration" could be filed, stating that the agency would not prepare an environmental impact statement. Public pressure has changed this decision in specific instances. Several lawsuits brought by the local environmental groups against the Federal Power Commission have forced the preparation of environmental impact statements for proposed conventional power plants for which the EPA had filed an earlier negative declaration.

Congressional interest in solid waste lagged behind the concern for abatement of air and water pollution. It was not until 1965 that Congress passed the Solid Waste Disposal Act. This law and amendments by the Resource Recovery Act of 1970 initiated Federal action in this rapidly growing problem area. Unlike Federal air and water quality legislation, this law was not regulatory. Instead, it provided funding for research, development, and demonstration programs concerned with resource and energy recovery from solid-waste. The Act set, as a national goal, the development of "new and improved methods of collection, separation, recovery, and recycling of solid waste, and the environmentally safe disposal of nonrecoverable residues". Initially the implementation of the Solid Waste Disposal Act was a joint venture of the Departments of Interior and Health, Education and Welfare. With the establishment of the U.S. Environmental Protection Agency (EPA) in December of 1970, the administration of this act and the Resource Recovery Act passed to the EPA.

The Clean Air Act of 1970, as amended, provided new air pollution abatement regulations and has had a great effect on industry. The act established national primary and secondary ambient air quality standards for 10 specific pollutants from any source, as well as setting more stringent standards of performance for new stationary sources. Of particular significance to the area of solid-waste disposal were the standards for new incinerators and fossil-fuel fired steam generators.

The Federal Water Pollution Control Act (FWPCA) of 1970, as amended, provided even more powerful water pollution regulations. The bill directed the EPA to establish criteria and procedures for the adoption of Federal water quality standards necessary to "protect the public health or welfare". Initially the act required the States to adopt water-quality standards and a plan of enforcement which was consistent with criteria of the Federal act for interstate waters within their jurisdiction.

The FWPCA amendments of 1972 extend effluent limits beyond that required for human health and welfare and will have major implications. Essentially, the act provides that by 1983 "the discharge of any pollutants by any person shall be unlawful". Pollutants are defined in the act as "dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal and agriculture wastes". The act provides that publicly-owned treatment plants will achieve this effluent limitation by July 1, 1977, and that other than publicly owned treatment plants will achieve the limitations by July 1, 1983. The regulations further state that the Administrator of the EPA must require the "best practicable control technology currently available" to achieve the 1977 limitations. Attainment of the 1983 limitations required "the application of the best technology economically achievable which would result in reasonable progress toward the national goal of eliminating the discharge of all pollutants".

The wording of the law is sufficiently vague as to raise questions as to what constitutes a "zero discharge" and to what extent the regulations would be enforced. It is, however, strong enough that spokesman for industry have objected that the costs involved would be excessive. The Council on Environmental Quality has estimated the cost of this program from 1971 to 1980 would be $287.1 billion. Nelson Rockefeller has estimated the cost for zero discharge in New York alone would be over $225 billion dollars and in excess of 2 trillion dollars for the entire country (ref. 2-21).

2.3.4 ANTICIPATED ENVIRONMENTAL REGULATIONS

The EPA believes that existing air and water pollution laws are adequate. The Clean Air Act of 1970, the Federal Water Pollution Control Act of 1970, and the Marine Protection Research and Sanctuaries Act of 1972 and amendments to each provided, if not the actual standards, the enabling mechanism to deal with emissions of hazardous material into the air and surface waters from point sources. However, Federal, state, and local regulation of the land disposal of wastes may be characterized as either inadequate, incomplete, or nonexistent. The lack of land disposal regulations coupled with increasingly more stringent air and water pollution standards has increased the pressure on land disposal sites to accept more and varied wastes. This situation encourages the use of land as the ultimate sink for harmful materials which must be removed from air and water. In the absence of adequate controls, economic considerations have favored cheap disposal methods which are frequently the most environmentally unacceptable, such as landfills, injection wells, and surface holding ponds. These practices are undertaken at the risk of poisoning groundwater aquifers and adjacent bodies of surface water.*

Because of this problem, the EPA is seeking the authority to regulate land disposal, particularly the disposal of extremely toxic wastes. The proposed Hazardous Waste Act of 1973 would regulate the transportation, storage, recycling, detoxification and/or ultimate disposal of nonradioactive toxic wastes as a Federal-state partnership. While the proposed legislation would initially affect waste materials not ordinarily found in municipal refuse, the EPA believes that the disposal of municipal solid waste must also be controlled. Hazardous wastes must be diverted from the normal municipal waste stream and treated under controlled conditions to insure that no irreparable damage is done to the nation's health and environment.

In addition to the legislation already proposed, the EPA hopes to establish, within the next few years, minimum standards for the sanitary landfill of nonhazardous wastes. These standards would serve as a guide for legislation at the state level (ref. 2-22). Although some areas do have landfill standards, unfortunately too many are based on aesthetic considerations rather than pollution hazards (ref. 2-11). Standards should be based on the engineering properties of enclosing rock and soil units, with a careful consideration of the long-term effects of leachate on local surface water systems and plant and animal life. Vigorous enforcement of standards, where they exist, is rare and usually there are no rules which apply uniformly to both public and private operators. To be successful, all land disposal sites must be controlled by strong regulations backed by enforcement powers. If strong nationwide regulations are not enacted, the problem will not be solved; it will be merely shifted from locality to locality as individual units of government pass more environmentally demanding standards.

Going beyond standards for new landfills, proposed legislation may require remedial maintenance for polluting landfills which have long been abandoned. In the future, leachate may have to be removed from the ground and sent through a water treatment plant, and offending solids dug up and removed. The final costs of today's supposedly cheap landfills may be paid some years hence.

All currently known methods of energy recovery, recycling, or disposal of solid waste produce at least some residue which must be landfilled. For this reason, anticipated future uniform, environmentally sound land disposal methods should be considered when planning any waste management system.

2.3.5 ENVIRONMENTAL REGULATIONS SIGNIFICANT TO ENERGY GENERATION FROM SOLID WASTE

Any existing or proposed installation designed to recover energy from solid waste will have to meet state-Federal air and water quality standards applying to any industrial plant. If the energy generating process represents a hybrid between conventional systems and new "energy recovery from refuse technology", it may be subject to additional or unique combinations of existing regulations.

All energy generating sources, existing or new, must at least meet Federal primary and secondary ambient air quality standards regardless of their location. Absolute minimum air quality standards will depend on the locality of an individual installation, since states are empowered to establish air quality regulations which are more stringent than the Federal standards. "Ambient air" refers to that portion of the atmosphere which is external to buildings, and to which the public has access. The Federal act defines "primary ambient air quality standards" as that quality which is necessary with an adequate margin of safety, to protect public health. It is usually established as an annual average weight of pollutant per unit volume of air, per unit of time, or as maximum concentration

*Numerous documented case studies are cited in the 1974 Report to Congress on Disposal of Hazardous Wastes (ref. 2-12).

which may be exceeded not more than a set number of times per year. "Secondary ambient air quality standards" are defined as the levels of air quality necessary to protect the public welfare from known or anticipated adverse effects of a pollutant. These are usually established as the maximum number of short-term high-concentration emissions which are allowable without adverse effects on public health. Their purpose is to allow for occasional accidental or emergency emissions within a system. Both sets of standards are subject to revision at anytime by the EPA if additional information deems it necessary to protect public health.

The Clean Air Act of 1970 as amended has established standards for 6 specific pollutants which might be expected in emissions from either an incinerator or pyrolysis plant. They are: sulfur oxides (measured as sulfur dioxide), particulate matter, carbon monoxide, photochemical oxidents, hydrocarbons, and nitrogen dioxide) (see Table 2-1 for details). Later amendments have set emission standards for other hazardous air pollutants, i.e. asbestos, mercury, and beryllium, which would not ordinarily be emitted from plants generating energy from refuse. Additional emission standards for other materials, i.e. hydrogen chlorides, other acids, chlorine gas, flourides, polynuclear organic compounds of a number of heavy metals which might be present in municipal refuse in quantities sufficient cause problems, have been suggested, but have not yet been promulgated (ref. 2-23).

If a new stationary source (defined as any new installation which emits any air pollutant) is planned, it must be designed to meet "Federal emission standards of performance of new stationary source" as defined by Section 60 of the Clean Air Act of 1970 as amended. Any facility which is modified to change its method of operation is also considered by the Act to be a new stationary source. For most types of industrial installations this regulation does not impose more stringent air quality standards unless the installation is a new fossil-fuel fired steam generator, incinerator, portland cement plant, nitric acid plant or sulfuric acid plant.

Coal-fired steam boilers modified to burn both refuse and coal, such as the prototype system operated by Union Electric in St. Louis, are considered new stationary sources under the provisions of Section 60 of the Act mentioned above. The St. Louis prototype, even though it is an EPA demonstration project, has encountered regulation problems because EPA has not yet decided if the hybrid system should be classified as a new fossil-fuel fired steam generator or as a new incinerator (ref. 2-24). Air quality standards are more stringent for new incinerators (see Table 2-2) than for new steam boilers. The decision in this matter will have a significant impact on the operating costs of such plants. A final ruling clarifying this situation is required before we would expect to see any additional conversion of coal-fired to coal-refuse-fired boilers.

Although the Clean Air Act specifically defines more stringent emission standards for new incinerators, no mention is made of pyrolysis plants. "Incinerator" is defined as "any furnace used in the process of burning solid waste for the primary purpose of reducing the volume of waste by removing combustible matter". This language might be interpreted to

TABLE 2-1
NATIONAL PRIMARY AND SECONDARY AMBIENT AIR QUALITY STANDARDS

Pollutant	Levels not to exceed: Primary standard	Levels not to exceed: Secondary Standard	Comments
Sulfur Oxides (measured as sulfur dioxide)	80 micrograms/m^3 (0.03 ppm)	60 micrograms/m^3 (0.02 ppm)	Annual arithmetic mean
	365 micrograms/m^3 (0.14 ppm)	260 micrograms/m^3 (0.1 ppm)	Maximum 24 hour concentration not to be exceeded more than once per year.
		1,300 micrograms/m^3	Maximum 3 hour concentration not to be exceeded more than once per year.
Particulate Matter	75 micrograms/m^3	60 micrograms/m^3	Annual geometric mean
	260 micrograms/m^3	150 micrograms/m^3	Maximum 24 hour concentration not to be exceeded more than once per year.
Carbon Monoxide	10 milligrams/m^3 (9 ppm)	Same as primary	Maximum 8 hour concentration not to be exceeded more than once per year.
	40 milligrams/m^3 (35 ppm)	Same as primary	Maximum 1 hour concentration not to be exceeded more than once per year.
Photochemical Oxidants	160 micrograms/m^3 (0.08)	Same as primary	Maximum 1 hour concentration not to be exceeded more than once per year.
Hydrocarbons	160 micrograms/m^3 (0.24 ppm)	Same as primary	Maximum 3 hour concentration (from 6 to 9 a.m.) not to be exceeded more than once per year.
Nitrogen	100 micrograms/m^3 90.05 ppm)	Same as primary	Annual arithmetic mean

Source: Reference 2-23.

*Reference methods for determining pollutant levels are described in detail in appendices to Part 50 of The Clean Air Act of 1970.

TABLE 2-2
STANDARDS OF PERFORMANCE FOR NEW STATIONARY SOURCES

	Fossil-Fuel Fired Steam Generators	Incinerators
Paticulate Material	Must not exceed 0.10 lbs. per million B.t.u. heat input (0.043 g per 10^6j) maximum 2 hour average	Must not exceed into the atmosphere in excess of 0.08 g / s.c.f. (0.10 g./m^3) corrected to 12% CO_2 maximum 2 hour average.
Visible Emmissions	Not greater than 20% opacity, except that 40% opacity shall be permissible for more than 2 minutes in any hour.	None stated.

Source: Part 60, The Clean Air Act of 1970

include pyrolysis plants which produce gas, oil or char by the incomplete combustion of municipal solid waste. Since large-scale pyrolysis of solid waste is a relatively new technology (see Chapter 3), any installation would be new, and required pollution control devices could be incorporated into the initial system design. This would probably be much simpler than upgrading pollution controls on a modified existing system, as was required on the modified Union Electric coal-refuse-fired steam boilers.

All current state and Federal water quality regulations must be met by an existing or proposed plant which generates energy from solid waste. No unique water quality regulations are anticipated for this type of operation. However, all plants must be able to attain a "zero discharge" of pollutants into any body of surface water by 1977 or 1983, depending on whether the plant is publicly or privately owned.

Internal environmental standards must also be considered for any existing or new energy or resource recovery system. These standards mainly concern the safety and health of employees. Virtually all refuse disposal or refuse conversion installations are subject to compliance with the rules and regulations of the Occupational Safety and Health Act of 1970 (OSHA). This Act covers a wide range of industrial activities and regulates general housekeeping, floor openings, means of egress, noise, temperature, personal safety equipment, sanitary facilities, and electrical safeguards. The OSHA regulations, like most pieces of environmental legislation, require that states adopt the Federal standards or submit for Federal approval a plan of their own. State regulations may be more stringent than Federal regulations. Local safety standards should be assessed during the design phase of any new installation.

Certain aspects of worker safety and health peculiar to the refuse disposal industry (i.e. the microbiological quality of air in the work environment) do not appear to be covered in existing regulations (ref. 2-25). Alvarez (ref. 2-26) has suggested that it is time for the waste-disposal industry to take a critical look at itself with respect to existing OSHA regulations and proposed standards. He believes that OSHA may target the industry for increased inspections and regulations because of the high injury rate of municipal employees involved in the disposal of solid waste.

2.4 FEDERAL POLICIES AFFECTING ENERGY AND RESOURCE RECOVERY FROM SOLID WASTE

A number of Federal laws and regulations discourage energy and resource recovery from municipal solid waste. While such policies do not prevent energy and resource recovery, they do give advantages to the use of virgin resources which discourage the use of products made from secondary materials. Examples of these policies include freight rates for secondary materials, depletion allowances, rules of capital amortization, and Federal policies fixing the price of natural gas.

Although it is unclear exactly how and to what degree policies such as these discourage energy and resource recovery, they would seem to have sufficient impact to warrant careful consideration. Each is examined in some detail below.

2.4.1 Freight Rate Policies for Virgin and Secondary Materials

It is not possible at present to demonstrate that higher freight rates cause an actual decrease in the amount of secondary materials; the cost of shipment is much higher than for equivalent virgin materials. It is difficult to pinpoint any one factor as responsible for these differences in freight rates. Ratemakers allegedly take into account a number of variables when establishing the cost of services. For example, such factors as weight, insurance costs, liability to damage, combustibility, susceptibility to theft, ease of loading, excessive weight and length, and frequency of shipment must be considered. The higher costs for secondary materials, when compared with virgin materials, may be due to one or more of the above factors. Thus, higher freight rates do not by themselves constitute proof of discrimination. Secondary materials may simply have distinctly different transportation characteristics which result in higher transportation costs.

If, however, one compares the cost of shipment to the revenue generated from virgin and secondary materials, some interesting patterns develop. Iron ore, when compared to steel and iron scrap, contribute <u>less</u> revenue; wood pulp, when compared to waste paper, contributes <u>more</u>; glass sand, compared with glass cullet, contributes <u>less</u>; aluminum ingots compared with scrap aluminum contribute <u>more</u>. When natural and synthetic rubber are compared with scrap and reclaimed rubber, scrap contributes <u>less</u> and reclaimed contributes <u>more</u> than natural and synthetic rubber.

The EPA has attempted to determine freight rates as a percent of delivered price of virgin and secondary materials. It reports that:

> For secondary materials of lower value, such as scrap iron, wastepaper, glass cullet, and scrap rubber, the freight rate is a substantial fraction of the overall delivered cost. For these materials, a significant adjustment of freight rates could cause a significant price change; and, if the demand is elastic, a corresponding change in consumption. These materials would be affected most severely by a discriminatory rate structure. For secondary materials of higher value, such as aluminum and reclaimed rubber, the freight rate is a smaller fraction of cost, and consumption would be expected to be less sensitive to freight charges (ref. 2-27).

The general conclusions of the EPA in this matter are as follows:

1. Freight rates are higher for some secondary materials. Rail rates are higher for scrap iron, glass cullet and reclaimed rubber and ocean rates higher for wastepaper.

2. Freight rates represent a substantial fraction of the cost of using many secondary materials (scrap iron, wastepaper, glass cullet, and scrap rubber).

3. While there is some potential for discrimination, there is no direct evidence to indicate that higher freight rates result in a reduction of recycling.

4. Further study is needed to determine the extent to which there is discrimination against secondary materials.

2.4.2 Federal Tax Policies for Virgin Materials

A number of Federal tax policies give benefits to industries engaged in the extraction of virgin materials. These policies were originally established in 1926 to encourage the development of domestic natural resources which were thought essential for national defense. At the present time, such Federal tax policies apply only to the extraction of natural or virgin resources, and not to the same material recovered from secondary sources. Thus, aluminum refined from natural ores is covered by this policy but aluminum recovered from solid waste is not. Examples of these policies are discussed next.

2.4.2.1 DEPLETION ALLOWANCES

The depletion allowances on the extraction of virgin minerals allow an affected industry two options. It may opt to deduct for tax purposes a portion of the investment <u>cost</u> of acquiring the mineral deposit from the yearly gross income. This is called cost depletion and is equivalent to methods of capital depreciation used in other industries. On the other hand, the industry may opt to deduct each year a fixed percentage of gross <u>income</u> generated. This is called a percentage depletion. The percentage allowed varies according to the industry. In the petroleum industry, the percentage depletion allowance is 22 percent a year. Clearly, a firm which may claim a tax deduction for a portion of its gross income enjoys an advantage over firms which may only claim deductions for actual capital costs.

2.4.2.2 EXPENSING CAPITAL EXPENDITURES

In most nonmineral industries, capital improvements are not deducted from yearly income, but added to capital assets and recovered through yearly depreciations. The mineral industries, however, enjoys a special rule. They may deduct from current income the entire cost of development of assets in the year the cost was incurred. This allows them to recover a major portion of invested capital even before the investment reaches the production stage.

2.3.2.3 CAPITAL GAINS TREATMENT

In most industries, any capital gains received from sale of property is subject to a maximum rate of 48 percent income tax. In the minerals industries, however, the capital gains tax is reduced from the normal 48 percent. The amount of capital gains tax reduction varies according to the industry. In the case of the timber industry, the tax is reduced to 30 percent. Similar reductions are found in other industries.

2.4.2.4 FOREIGN TAX ALLOWANCES

Industries doing business in foreign countries can receive special tax concessions under one of several programs. These special tax concessions have encouraged investments in foreign mineral industries. Such tax concessions make foreign produced minerals more competitive with domestic minerals.

2.4.2.5 IMPACT OF TAX ADVANTAGES

The four Federal policies (depletion allowances, expensing capital expenditures, capital gains treatment, and foreign tax credits) are examples of favorable treatment of minerals industries. The question which must be answered is the extent to which these policies encourage investment in virgin materials and discourage use of secondary materials.

The EPA in its Second Report to Congress (ref. 2-27) attempts to estimate the total tax benefits from these four sources on a dollar per ton basis and total dollars. These estimates are displayed below in Table 2-3.

While these estimates do not determine the degree to which Federal tax policies encourage investments in virgin material and discourage investment in secondary materials they do point out the competitive advantage enjoyed by the virgin materials industries. If the use of secondary materials is to be encouraged some consideration must be given to equalizing this competitive advantage.

2.4.3 FEDERAL POLICIES REGULATING NATURAL GAS

The Federal Power Commission (FPC) regulates the transportation of natural gas in interstate commerce as well as "the sale in interstate commerce of natural gas for resale for ultimate public consumption for domestic, commercial, industrial or any other use, and. . .natural gas companies engaged in such transportation or sale"

TABLE 2-3
SUMMARY OF ESTIMATES OF TAX BENEFITS, 1970*

Product	Unit Value	Total value (millions of dollars)
Paper	\$0.899 per 907 kg (short ton)	37.75
Petroleum	\$0.350 per $0.159m^3$ (barrel)	1,350.00
Natural Gas	\$0.022 per $28.3m^3$ (10^3 ft^3)	450.00
Iron Ore	\$0.748 per 1016kg (long ton)	96.64
Coal	\$0.142 per 1016 kg (long ton)	80.59
Bauxite (used for aluminum)	\$1.496 per 1016 kg (long ton)	20.96
Sand (used for glass)	\$0.082 per 1016 kg (long ton)	0.86

*Adapted from: EPA, Second Report to Congress (ref. 2-27, p.33).

(ref. 2-28). This regulation covers about 60 to 70 percent of all natural gas consumed in the United States. Gas produced and consumed wholly within a producing state is not subject to the FPC regulation, while gas shipped to another state is covered by this FPC regulation.

The FPC regulatory power could affect solid-waste energy recovery systems in two ways. First, the FPC has jurisdiction over the transmission of electrical energy in interstate commerce. Any organization which interconnects with a "public utility" transmitting electrical energy into interstate commerce may come under the jurisdiction of the FPC. Thus, if a pyrolysis plant produces a gas, and sells that gas to an electrical generating system which comes under the jurisdiction of the FPC, that pyrolysis plant may also be subject to the FPC regulations (ref. 2-29). Additionally, if the pyrolysis gas were simply shipped into interstate commerce rather than sold to an electrical utility, the pyrolysis producing plant might be subject to FPC regulations. Since no large refuse pyrolysis plants have ever been built, regulations in this area are uncertain.

The second FPC influence relates to its price setting power. For a number of years, the FPC has set the price of natural gas shipped into interstate commerce at 34¢ per 1.055×10^9 joules (10^6 BTU). Recently, this price was raised to 46¢ per 1.055×10^9 joules (10^6 BTU) on new production. This Federal policy may have an effect upon the price of any fuel gas produced by the pyrolysis of solid waste.

This effect could take one of two forms. First, natural gas produced and used within a state (intrastate) is not regulated by Federal price fixing policy and the price of such natural gas in producing states has risen well above the interstate Federal ceiling. In these states, gas produced by pyrolysis probably could be competitively priced with natural gas. Second, in nonnatural gas producing states, the price would be fixed by Federal regulation and pyrolysis gas might not be competitive with the relatively cheap pipeline gas. However, in nonproducing states the supply of natural gas has become increasingly uncertain and often scarce because many suppliers are reluctant to sell at the Federal ceiling price. Thus, it is possible that pyrolysis gas might be priced above the FPC ceiling and remain competitive. Demand for interstate natural gas exceeds available supplies. Many industries may accept a higher priced pyrolysis gas in place of the lower priced, but unavailable, natural gas. Another competitive advantage of pyrolysis gas is the possibility of contractually guaranteed supply. If a temporary shortage of natural gas occurs, FPC policy requires utilities to give priority to residential customers; service to industrial customers may be curtailed. Pyrolysis gas, as an intrastate commodity, is not subject to this constraint.

One additional regulation should be mentioned. In some states the price of natural gas is set either by a state agency or by cities through exclusive franchises. In Texas, for example, cities set the price of natural gas sold to customers within the city. In some cases the price established by city governments is about equal to Federal price. Thus, in some cases even natural gas producing states may have unnaturally low prices which could affect the price of pyrolysis gas produced from an energy recovery system.

2.4.4 Federal Procurement Policies and the Secondary Materials Market

One of the largest problems to overcome in recycling is that of market uncertainty. Market values of salvageable goods and materials fluctuate greatly. Since the Federal Government is the single largest consumer of many products it has been suggested that Federal procurement of recycled materials could be used to establish a stable market for products produced from secondary materials. This has been done with paper products and rubber tires.

The EPA has studied the effect of existing procurement policies and potential Federal policies on market demand for secondary materials. They conclude that while the Federal Government is the single largest consumer of many products it does not constitute, by itself, a sufficient portion of the market to create a demand for recycled materials (ref. 2-27). State and local governments and other consumers must join the Federal government in the effort to create a market for recovered resources.

Additional research funds to improve recovery techniques and develop uses for secondary materials could be provided by the EPA and other government agencies. In Fiscal Year 1973, only four such grants were issued by the EPA's Resource Recovery Technology program. Such research funding might have an effect similar to Federally funded research to improve agricultural productivity. Long term benefits from resource conservation would provide the economic justification for such expenditures.

2.4.5 Federal Policies Encouraging Development of Recovery Technology

Until recently the technology related to energy recovery from municipal solid waste has been limited primarily to steam recovery through incineration. Twelve such systems are known to exist at the present time, four of which are newly developed (ref. 2-27, p. 28). The primary drawback to steam recovery is the difficulty of marketing and transporting the product. In many cities, there is simply no market for steam.

Because of the market problems associated with steam, several new technologies are being developed to produce disposal systems which will generate more saleable products. Examples of these new technologies are discussed in detail elsewhere in this report and will not be discussed here. They can be placed into the following general categories:

1. Shredded waste as a fuel supplement.
2. Wet pulping to produce a fuel supplement with potential for fiber recovery.
3. Pyrolysis to produce gas or liquid fuel.
4. Incineration to produce gas for turbine electrical generation.
5. Biodegradation to produce methane gas.
6. Biochemical conversion to produce glucose.

Today at least 18 cities have energy recovery systems under construction and 20 other municipalities are known to be evaluating such systems (ref. 2-27, p. 41).

Six of these systems under construction have been in part, stimulated by EPA Demonstration Grants (ref. 2-30). These are summarized in Table 2-4.

TABLE 2-4
SOME ENERGY RECOVERY SYSTEMS UNDER CONSTRUCTION

City	Process	Funds Federal	Funds Local
1. St. Louis, Missouri	Shredded waste as coal supplement	$2,580,026	$1,380,518
2. Wilmington, Delaware	Shredded waste as a fuel substitute or as compost	9,000,000	4,760,000
3. Franklin, Ohio	Wet pulping for material recovery	2,100,000	1,000,000
4. San Diego County, Calif.	Pyrolysis to produce fuel oil	2,962,710	2,050,000
5. Baltimore, Md.	Pyrolysis to produce gas to generate steam	6,000,000	6,177,000
6. Lowell, Mass.	Incineration residue separation	2,384,000	793,000

Source: EPA, Second Report to Congress (ref. 2-27, pp. 91-97)

In addition to these programs, the EPA also has funded several other demonstration projects of some significance. These are summarized in Table 2-5.

There is little doubt that these EPA grants have helped advance the "state of the art" of energy and resource recovery. Further grants will probably be forthcoming under two bills presently being considered by Congress (ref. 2-31).

While private capital markets may provide the necessary resources to develop further energy recovery systems, the technical and economic uncertainty, the lack of management and operational expertise at the local level, local physical conditions (e.g. low cost landfill sites) and unique local political conditions may prevent the tapping of such capital markets unless some additional Federal fiscal incentives are provided.

2.5 STATE AND LOCAL LEGAL AND POLITICAL PROBLEMS AFFECTING ENERGY AND RESOURCE RECOVERY FROM SOLID WASTE

Disposal of municipal refuse has for many years been the primary responsibility of local governments. In the past, disposal was solved by open dumping and/or burning, but these processes caused health and air pollution problems which forced

TABLE 2-5
SOME DEMONSTRATION PROJECTS OF SIGNIFICANCE

Project	Process	Funds
1. Combustion Power Co., Menlo, Calif.	Incineration to produce gas for turbine generation	$6,000,000
2. Franklin Institute, Philadelphia, Pennsylvania	Ballistic separator to mechanically separate shredded refuse to recover paper fiber	135,000
3. Vanderbilt University	High-energy electromagnetic separator to separate nonferrous metals	435,481

Source: EPA, Second Report to Congress (ref. 2-27, p. 98) cities to turn to sanitary landfills and incineration as alternate processes. More recently, Federal air pollution standards and rising costs have forced some local governments to abandon incineration as a method of disposal. Other state and Federal standards are closing landfills. Increasingly there is debate in Congress and elsewhere regarding future hazards from existing landfills. Additional regulations, such as those proposed in the EPA's Report to Congress on the Disposal of Hazardous Wastes (ref. 2-12), may force the closing of other landfills.

Thus, the present and possible future closing of landfills and some incinerators are but two factors which are forcing city governments to give attention to the recovery of resources from mixed municipal refuse through either energy generation or recycling. However, before either of these options becomes acceptable to many local governments a number of very important political problems must be faced. This section examines those problems.

2.5.1 New and Unproven Technologies

Some city officials have expressed reluctance to invest in multi-million dollar disposal plants of unproven technology and reliability. Reliability seems to be the most important factor. The amount of refuse generated in a city is relatively constant, and any solid waste disposal system must meet the "garbage" problem on a day-to-day basis. A city cannot stop collecting garbage for a week or two in order to iron out equipment problems.

Additional reluctance has been expressed by city officials regarding the lack of management and operational experience necessary for such disposal plants. With technologies yet unproven the skills necessary for operation are also uncertain.

Many city officials seem to be taking a "wait and see" attitude. If some of the processes being developed under EPA Demonstration Grants prove successful, this reluctance will be overcome. However, for the present these new disposal technologies are viewed with some skepticism.

2.5.2 Noncrisis Attitude of Citizens and City Officials

In areas where landfill is a relatively cheap method of disposing of solid waste, city officials are especially reluctant to spend millions of dollars on unproven technologies. In such areas both citizens and city officials do not view solid waste as a problem of crisis proportions. If a city can continue to landfill for as low as $2.50 per 907 kilogram (ton), suggestions for energy recovery systems with estimated costs as low as even $4.00 per 907 kilogram (ton) would be politically unacceptable. Until some crisis develops (such as new environmental standards on landfills which increase the costs), cities will not view energy recovery as a viable option.

Another point of view frequently advanced is as follows: "Even though energy and resource recovery cost more, it is the 'right' thing to do from an environmental standpoint and it saves our limited resources". Although many persons would agree with that opinion it is difficult to sell politically. The average citizen and some members of the scientific and technical community are as yet unconvinced that resources are limited. Until the limited nature of nonrenewable resources becomes more widely accepted, energy and resource recovery systems which cost more than conventional landfill methods will not be politically viable. In the meantime, any change in disposal technology will most probably result from pollution regulations and short run economic pressures.

2.5.3 Problems in Developing Area-Wide Organizations for Energy and Resource Recovery

2.5.3.1 ECONOMIES OF SCALE NEEDED

Studies by the EPA and others have indicated that in order to have an efficient energy recovery plant at least 453 metric ton/day (500 ton/day) of MMR must be processed (ref. 2-27, p. 39). At the rate of 1.7 kilograms (4 lb.) per person per day* it would require a city with a population of 250,000 to generate 453 metric tons. Only about 20 percent of the total population lives in cities containing populations of 250,000 or more, a total of 56 such cities. There are 125 Standard Metropolitan Statistical Areas (SMSA's) which account for 62 percent of the total U. S. population and have sufficient population to generate the 453 metric ton/day of MMR needed for efficient energy recovery. This means that in 69 SMSA's containing 42 percent of the population, area-wide

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*Although each person in a household produces an average of 2.8 lb. per day of MMR, total MMR, including commercial solid waste, averages 1.7 kilograms (4 lb.) per person per day.

cooperation among the various governments in the regional waste shed would be necessary for efficient energy and resource recovery.

2.5.3.2 POLITICAL PROBLEMS OF REORGANIZATION

Almost all SMSA's in the United States have many units of government. They are "fragmented" into many small jurisdictions, with no one unit responsible for the entire metropolitan area.

The job of bringing these units together to discuss an area-wide problem is, in itself, difficult; reaching agreement is often impossible. Studies of intergovernmental cooperatives indicate that an agreement is most often achieved when (1) the issue has low controversey (such as street numbering consistency), (2) there is little immediate financial cost (such as mutual agreement pacts for exchange of fire equipment in emergencies) or (3) the issue has reached crisis proportions (such as planning for an area-wide transportation system) (ref. 2-32). To date, most cooperative agreements by governments in metropolitan areas tend to be informal rather than formal. This informality allows local governments to withdraw at any time, thus reducing the usefulness of such agreements. Formal agreements are often contractual in nature, subject to re-negotiation, and by no means permanent.

The degree to which communities in a small metropolitan area cooperate is also affected by the social, partisan, and policy differences between communities in the area. If the communities differ in socio-economic status, have strong partisan differences, or pursue differing municipal policies, then the difficulty of reaching agreement is increased.

Finally, the degree of cooperation is also affected by the type of issue. Local governments may cooperate on issues such as area-wide water and sewage systems, but be unwilling to create an area-wide school or police system.

To what degree will local governments in a metropolitan area be willing to cooperate to create area-wide solid-waste management systems? A recent study by the Advisory Commission on Intergovernmental Relations (ACIR) indicates that area-wide cooperation on solid waste disposal is quite promising. The issue, according to the ACIR, has no adverse social implications and a relatively low inter-city conflict potential (ref. 2-32). Thus, prospects for area-wide special districts which could achieve the minimum 453 metric ton/day necessary for efficient solid waste are good.

2.5.3.3 POLITICAL PROBLEMS AFTER CREATION OF AREA-WIDE AGENCIES

The potential political problems for metropolitan area-wide disposal agencies lie not in creating such agencies but in the decisions such an agency must make. Disposal site selection will remain a difficult problem and perhaps increase as proposals for large energy and resource recovery plants are forthcoming. However, finding one or two sites for large capacity disposal plants may be easier than finding small landfill sites.

Fledgling metropolitan disposal agencies will undoubtedly experience a myriad of additional political conflicts. A dispute between Monroe County, New York, and local private haulers is a good example. Monroe County passed an ordinance requiring all solid waste collected in the county to be dumped only at designated disposal sites (ref. 2-33). This was done in order to obtain the volume of solid waste needed to make the county-wide disposal facility profitable. Objections to this county ordinance have been raised in a lawsuit by private collectors and a disposal site operator. These private firms have been licensed by the municipalities in the county under the home rule ordinance power. Normally, home rule ordinance power cannot be superceded by other governmental units in the state. The private haulers contend that the county has superceded the home rule ordinance powers of cities by passing an ordinance requiring dumping only at designated areas. The county contends that the municipalities have only licensed <u>collection</u>, not <u>disposal</u>, and that the home rule provision of the state constitution is not superceded. The case is pending in court (ref. 2-34).

Local decision makers should consider this type of conflict as a potential problem which might develop from the creation of an area-wide disposal authority. Ordinances or other laws restricting disposal to designated areas should be carefully written and potential conflicts with municipalities and private haulers negotiated in advance.

In the past, solid waste has not been viewed as a resource but as a liability. In the future, solid waste may be viewed as a resource. If so, it will no longer be a "free good" which people pay to have removed, but a valuable resource which can be owned and sold. When this happens conflicts will arise between government agencies and private interests over the ownership of municipal garbage.

2.5.4 LACK OF PLANNING IN SELECTION OF DISPOSAL SITES

All solid waste disposal systems require land utilization. Regardless of the method of disposal used, the process of disposal site selection has become increasingly difficult for a number of reasons, not the least of which is citizen protest. While all citizens want their solid waste picked up, few want the city to put it down anywhere near their home. In the past the problem of site selection (generally for landfills or dumps) was solved by locating such facilities in low-income areas. In recent years residents of low-income areas have begun to object to the location of disposal sites in their neighborhood.

At least part of the problem of citizen protest could be solved if solid waste disposal site selection were included as a normal part of a comprehensive land use plan. Proposals for disposal sites near residential neighborhoods may be viewed as a threat to property values, a potential health or environmental hazard, or a possible source of danger due to increased truck traffic in the area. If, however, the citizen were aware before he purchased his house of future planned disposal sites near his home he would have little recourse for protest.

In addition to reducing citizen protest over site selection, there are a number of other advantages to including solid-waste disposal sites as a part of the comprehensive planning process. Sanford M. Brown has suggested the following advantages (ref. 2-35):

First, disposal sites could be viewed as a "positive" land use rather than as a nonconforming use. This might develop into a zoning category for solid-waste disposal. Brown suggested the following zoning categories: Solid-Waste Processing-1 (SWP-1) to include recycling centers, transfer stations, truck storage, truck repair and central storage areas; SWP-2 to include composting plants, commercial incinerators, sanitary landfills; SWP-3 to include industrial incinerators, industrial landfills, municipal incinerators, modified landfills; and SWP-4 to include hazardous waste disposal.

Second, modified landfilling sites (necessary even if energy recovery is used) can be viewed as temporary only, with later conversion to recreation areas. This would provide cities with an interim landfill land use program. Areas that are not immediately useful as recreation areas could be landfilled first and converted later.

A third advantage would be to provide for solid-waste disposal sites before they are needed. Generally, most local governments do not begin to search for new sites until a crisis is reached. Long-range planning would avoid such crisis decisions which are often not the best of all possible decisions.

Finally, if planning for solid waste management disposal becomes an accepted part of the planning process, it would make it easier for an area-wide solid waste management agency to develop and function.

2.5.5 POTENTIAL PROBLEMS IN EXCLUSIVE FRANCHISES

While exclusive franchises do not necessarily create a significant problem to pyrolysis energy recovery, they are a problem which local decision makers should consider during the planning stage.

Traditionally state governments have allowed cities to grant franchises (contracts) to service corporations. These franchises may grant a company the exclusive right to distribute a product such as natural gas, electricity, telephone, etc. to all residents of the city. While not all franchises are exclusive, public utility franchises generally have this character.

If a municipality grants an exclusive franchise to a public utility, the city government may decide to furnish its <u>own</u> services without conflicting with the franchise. However, if a city decides to provide services to others, it may conflict with an exclusive franchise. Thus, if a municipality were to produce a pyrolysis gas from municipal refuse and sell that gas to customers normally served by a natural gas public utility, the city could be in conflict with the exclusive franchise. It might then be necessary for a city contemplating such a system to renegotiate the franchise with the natural gas public utility.

2.5.6 LEGAL LIABILITIES FOR PRODUCTS PRODUCED FROM MMR

A local government engaged in the conversion of MMR to some usable product will have to consider the problem of tort liability. Local governments in the United States traditionally have a limited tort liability when engaged in proprietary functions such as operating public utilities. Pyrolysis or resource recovery plants would fall in this category. When engaged in governmental activities, such as police or fire protection, there is normally little or no tort liability because cities are acting on behalf of the state.

As an example of this problem, assume that a local government produced a pyrolysis gas, and sold that gas to an electrical generating company. In the burning of that gas by the electrical company some toxic substance was discharged into the atmosphere causing death or injury to individuals. Who would be liable for this injury? Would the municipality (which produced the gas) or the electrical company (which burned the gas) be liable; or would they share joint liability? Would this be covered under normal product production liabilities? A report by C. W. Morck, Jr. indicates that in most states answers to these questions are uncertain (ref. 2-36).

Due to the heterogeneous nature of MMR, the risk of producing toxic substances in energy and resource recovery systems is plausible, and municipal officials writing contracts for the sale of products should consider this.* Customers may be reluctant to purchase such products unless the local government retains some liability.

2.5.7 Financial and Contractual Options Open to Local Governments

A number of technical options are available to local governments wishing to engage in energy and resource recovery from MMR. In addition to the problem of selecting the best technical option available to meet their needs, decision makers must also consider the financial and contractual options available. These options relate to the question of public versus private ownership. Should municipalities own the recovery system or contract with a privately owned system on a fixed fee per ton basis? There are a number of advantages to public ownership. These include:

1. Exemption from Federal and state income taxes
2. Tax free bonds
3. Lower interest rates on bonds
4. Sales tax exemption on equipment purchases
5. Fewer zoning problems
6. Exemptions from some state regulations affecting site location

*For a more detailed discussion of the possible dangerous substances which could be produced from MMR see Section 2.3 of this report.

Lower capital costs result from items 2, 3, and 4 above. Income tax exemptions will lower operating costs. Reduced zoning problems and exemption from state and local regulation may make the problem of site selection somewhat easier than that faced by privately-owned facilities.

There are also important disadvantages to public ownership of energy and resource recovery systems. One problem is that no property tax revenue will be derived from the facility. Local decision makers will have to determine if the loss of income from property taxes can be offset by the decreased capital and operating costs which accrue from public ownership.

Another disadvantage of public ownership is that local governments may find it difficult to attract the personnel necessary to operate highly technical equipment. Managerial problems associated with the operation of such a system may be difficult for cities to overcome.

Disadvantages to private ownership also exist. One disadvantage is related to time limitations on contracts. Local governments are usually limited by state law or local charters to contracts not to exceed an established number of years. Five years is a common limit. Longer contracts are possible, but voter approval is often required. A private company may be reluctant to invest millions of dollars in an energy and resource recovery plant if it could be guaranteed a contract of no more than five years. Obtaining voter approval for contracts of longer than five years may create problems for local officials. However, such voter approval for long-term contracts may be no more difficult than obtaining voter approval for capital bonds needed to construct publicly owned systems.

Another disadvantage of private ownership is that it is difficult for a city to develop a solid-waste plan extending beyond the time limits of a contract. Maximizing planning time by entering into long-term contracts may lead to other problems. Solid-waste problems may change significantly in a very few years. Cities bound by a long-term contract may be unable to respond effectively to changing conditions.

In addition to private or public ownership of refuse processing facilities, cities in some states are allowed to issue publicly backed capital bonds for privately owned facilities. Under this option, the local government raises needed capital by issuing revenue bonds backed by the credit of a private company. Such bonds used to enjoy the normal low interest rate and tax exempt status accorded all state and municipal bonds. The private company would repay the local unit of government which in turn would repay the bonds. Ownership of the recovery system plant would remain with the private company and thus would be subject to property taxes. Such a project would enjoy lower capital costs and produce property tax revenue. At the same time the city would be freed of the problems of management and operation of the system. Due to a recent ruling by the Internal Revenue Service, this option is not presently available to cities. However, legislation has been introduced into Congress which would change this IRS ruling.

2.6 PRODUCT DESIGN LEGISLATION TO REDUCE WASTE AT SOURCE

2.6.1 BACKGROUND

The economy of the 20th century United States has been an economy of affluence. The nation was blessed with an abundance of resources and an entreprenurial spirit which led to an exceptional capacity to produce and acquire goods. Changing patterns of consumption which equate increased consumption of goods with increased self-worth have made the solid waste problem more difficult each year. This, in turn, has been compounded by the growth in the nation's population. Not only are people consuming (and discarding) more now than they ever have, but there are more people consuming more goods.

In less affluent times possessions were cherished, maintained, and handed down from generation to generation. Now the emphasis is on newness, novelty, and convenience. Our culture is one which favors trivial or useless products (e.g. electric hog dog cookers), products which are easily broken (e.g. most plastic toys), products designed to be used and discarded (e.g. many ball point pens), products with designed obsolescence (e.g. American automobiles) and products which, when broken, are almost impossible to repair (e.g. many small domestic appliances). Two factors would seem to indicate the need for change in traditional American values. First, energy and many materials are becoming increasingly scarce and expensive. Second, solid-waste disposal costs are rising rapidly. For these reasons, legislation is needed on product design so that (1) the volume of material entering the waste stream is reduced by maximizing the useful life of products and eliminating the manufacture of trivial products and excess packaging, and (2) material entering the waste stream can be easily recovered for reuse or recycling. Several types of savings will accrue from these changes: (1) Collection costs will be somewhat reduced. (2) Disposal costs will be reduced. (3) Scarce material stockpiles will be preserved. (4) Energy demands will be reduced because recycling is less energy intensive than virgin material production (ref. 2-27).

We turn now to a discussion of two types of legislation. First, we consider legislation to reduce the amount of material in the municipal refuse stream. In this category we will discuss the recapping of tires and returnable bottles. Second, we examine legislation designed to alter the composition of municipal refuse and facilitate resource recovery. In this category we consider bimetallic cans and low-volume potentially hazardous material.

2.6.2 RECAPPING RUBBER TIRES

In 1971 approximately 250 million car, truck and motorcycle tires were taken out of service in the United States. Of those tires, 46 million (2.8 percent) were recycled by rubber reclaimers, 2 million (0.8 percent) were consumed by tire splitters, and 195 million (78 percent) were dumped (ref. 2-27).

Rubber tires are very difficult to dispose of properly. They are not biodegradable. Whole tires cannot be effectively compacted and buried in sanitary landfills. When tires are landfilled they tend to work their way to the surface and pop out of the landfill. Because of this, tires are often simply piled up in large heaps at dumps, a practice which is not only unsightly, but also provides breeding places for flies, mosquitos and rodents. Tires can be shredded and then landfilled or mixed with other refuse and burned.* However, the high costs of shredding have tended to discourage both.

Much of the current tire disposal problem could be alleviated if tires were retreaded rather than discarded. However, as a percent of new tire shipments, retreads have been declining. In 1968 only 17 percent of automobile tires and 28 percent of truck tires were retreaded. There are a number of reasons why a larger protion of tires are not retreaded.** Retreaded tires have a poor public image. Retreads, regardless of quality, are perceived by many persons to be inherently inferior to new tires. This view may be

*Tires cannot be burned by themselves in existing incinerators because of air pollution problems and because the fumes corrode and damage furnace walls.

**For a discussion of these points in more detail see Reuse and Solid Waste Management, by Pettigrew, et al, (ref. 2-37).

reinforced by some poor customer experience from the 1940's and 1950's before the retreading industry reached its present level of sophistication, or by the large number of separated tire treads which litter many interstate highways. Retreaders generally try to retread only the best grade of tires. Lower cost, lower quality new tires are eliminated rather than retreaded. However, most new tire manufacturers make a bottom-of-the-line tire which sells in the same price range. Faced with a choice between a nationally advertised and distributed bottom-of-the-line new tire and a brandless retread, consumers generally select the new tire, although the retread would be superior in quality.

Another problem limiting retreading is the fact that only about 35 percent of discarded passenger tires are suitable for retreading. Most consumers allow their tires to become too worn before replacing them. Impact with road hazards and driving on underinflated tires also damage the tire carcass and render it useless for retreading. Increased consumer interest in using retreaded tires and better tire care habits would substantially reduce the number of tires discarded each year.

From a technical standpoint, the main impediments to high quality retreading are variations in the type of rubber used in tire manufacture and size differences in the carcass and new tread. Both cause problems in achieving a permanent bond in retreads. Government standards on the composition of rubber used in tires may be of some help. The problem of tire sizing is somewhat more difficult to resolve by regulation. Tires have a tendency to "grow" as much as 7 percent of original tire width after a period of road use. This means that every tire must be measured prior to retreading and retreaders must maintain a very large inventory of different size curing rims and other materials.

If the problem of economically shredding discarded tires can be solved, those tires which are unfit for retreading may be used in the rubber reclaiming industry. Energy savings of up to 35 percent are possible when reclaimed rubber is substituted for virgin materials in rubber fabricating (ref. 2-37). The key to increased rubber reclaiming lies in finding a low cost way to fragment or shred discarded tires. It is not practical to ship whole, discarded tires; the volume to weight ratio is too high. If tires can be fragmented, then it becomes economical to ship the rubber. The picture is complicated by the fact that discarded tires are collecting at a large number of dispersed dumping locations. A successful shredder will have to be taken from dump site to dump site, reducing discarded tires to shipable form. According to Smerglia (ref. 2-38), some work is under way on a mobile cryogenic destruction system for tires, but this is still in the development phase and is not yet economically proven.

2.6.3 Nonrefillable Bottles

Although glass constitutes no more than 6 to 10 percent (by weight) of the municipal waste stream, discarded beverage bottles pose a serious litter problem (ref. 2-39). This is particularly true of the nonrefillable types which have grown yearly in popularity with the beverage container industry since the 1960's. Because there is no monetary incentive for individual users to accumulate and return, or for scavengers to collect nonrefillable bottles, many are disposed of in a haphazard and uncontrolled manner along public roadsides. In 1969, the EPA estimated that 2.2 billion bottles littered the nation's roadside.* Of these, the majority were the nonrefillable types. Because glass does not decompose, roadside litter by bottles is cumulative. Litter is also expensive to remove. In 1972 it cost an average of $45.00 per ton to collect street litter (ref. 2-41). It has been estimated that, to collect a six-pack of discarded beer bottles, a state must spend $1.95, more than the full pack price itself!

Much of the litter problem is due to the annual use of bottles. In the last decade the use of glass beverage containers has grown faster than either beverage consumption or population, with the use of "throw-away" bottles growing much faster than the returnable types (ref. 2-42). The public may consider nonrefillable glass beverage bottles more a problem of litter and visual blight than an actual waste of resources. However, an examination of glass production figures for 1967 reveals that a significant percentage of the U. S. annual production was discarded via the "throw-away" beverage bottle (ref. 2-39). Over 33 percent of all the glass produced in the country in 1967 went into the manufacture of beverage containers, the vast majority of which were discarded after just one use. Although the raw materials of glass (quartz sand, soda ash, and limestone) are abundant and low cost, discarding this much glass annually represents a significant net energy loss. Annual replacement of these throw-away bottles by an equivalent quantity of new glass also contributes a significant amount of pollution. The EPA

*For a detailed discussion of the composition of highway litter, see reference 2-40.

(ref. 2-27) estimates that the production of a ton of new glass requires 16 x 10^9 joule (15.2 x 10^6 BTU) of energy and produces 174 kilograms (384 lb) of mining wastes and 12.6 kilograms (27.8 lb) of air pollution.

Why has the use of the environmentally less desirable nonrefillable bottle continued to grow while the refillable bottle could significantly reduce this problem? The answer lies in the profit incentive in the glass container industry. Nonrefillable glass beverage bottles represent a huge potential market for glass manufacturers. This market has become increasingly more important in recent years as plastics and other material continue to be extensively substituted for containers which had traditionally been made of glass. Presumably, glass manufacturers would oppose the reduction or elimination of nonrefillable bottles which now account for much of the annual production of glass container products.

Three major methods have either been initiated or proposed to control the litter and waste associated with nonreturnable bottles. They are: (1) a mandatory deposit on all beverage containers, (2) the banning of nonrefillable beverage containers, and (3) a "litter tax" collected on each individual beverage container. Several states (Oregon and Vermont) and a number of cities have passed laws which require a deposit on all beverage containers, refillable as well as throw-away. Initial data on the Oregon experiment suggest a marked decrease in litter due to beverage bottles (ref. 2-43). The EPA has extrapolated the data obtained from these initial experiments. It estimates that Federal legislation requiring a 5¢ deposit on all beverage containers would result in a 60 percent reduction of litter (ref. 2-27). Resource and energy savings would be significant. This type of deposit would encourage the return of nonrefillable containers as well as the refillable type. This could be expected to bring pressure on manufacturers for the complete elimination of nonrefillable bottles. Repeated handling of refillable bottles (with an average life of 10-15 trips) is a labor intensive activity and would cost more than the one time distribution of nonrefillable bottles. However, the net energy savings and reduced litter cleanup costs associated with refillable bottles more than offset these increased labor costs.

2.6.4 Bimetallic Cans

Bimetallic cans pose some serious problems for resource recovery from MMR. These are primarily the familiar steel bodied "pop top" beverage containers. The top of the can is fabricated from aluminum. These cans are not suitable for recycling because there is no economically feasible way to separate the aluminum from the ferrous materials which are gathered magnetically in most resource recovery systems. The aluminum is an undesirable contaminant in scrap iron and steel and must be removed if the recovered iron and steel is to be recycled. The State of Oregon has solved this problem by legislation prohibiting bimetallic beverage containers. If resource recovery of ferrous metals from MMR is to become feasible on a wide scale, Federal legislation may be required to keep the bimetallic can out of the municipal solid waste stream.

2.6.5 Low-Volume Potentially Hazardous Material

A number of materials of great potential danger to human health are routinely dumped into the municipal waste stream. Even though these substances occur in small quantities, we cannot afford to neglect them, particularly when some are known to cause fatalities in laboratory animals in relatively small amounts. Certain plastics and fluorocarbon compounds, as well as pesticides and their containers, fall into this category. Existing and proposed legislation provides for special disposal treatment of the latter (ref. 2-44).

One of the greatest problems in this area is the lack of sufficient data on the toxicity levels of many of these materials. In most cases the reactions of these hazardous materials during incineration and pyrolysis are unknown.

Polyvinyl chloride plastics (PVC) are representative of this particularly troublesome class of materials, and PVC is a problem which has attracted considerable public attention recently. It has been claimed that this material releases phosgene and hydrogen chloride on burning (ref. 2-45). Experimental studies (ref. 2-46) find no evidence of phosgene, only hydrogen chloride which has been implicated as a major contributor of incinerator corrosion. Presumably this material would be equally troublesome to a pyrolysis system. Based on these problems, suggestions have been made to ban the use of PVC. A partial solution to this problem is the research which is attempting to find PVC additives which would neutralize the hydrochloric acid as soon as it is formed during combustion. More recent evidence now suggests that vinyl chloride may be a powerful carcinogenic agent (ref. 2-47). If true, this is sufficient grounds for completely banning PVC.

The dangers of such low volume potentially hazardous material in municipal waste should be carefully studied. If shown to be dangerous, these materials should be removed from the municipal waste stream by either restricting their use and disposal, or by a complete ban.

2.7 SUMMARY OF SOCIAL ASPECTS OF SOLID WASTE MANAGEMENT

In this chapter we have explored the social, political, environmental, and legal aspects of solid waste which we believe would either encourage or discourage the implementation of energy generation and resource recovery.

Social and Political:

The social and political factors which encourage or discourage energy and resource recovery are summarized in Table 2-6. Social attitudes and political problems are intimately interrelated and both are closely tied to cost factors. Citizen's attitudes are closely associated with their degree of knowledge of the problem of solid waste (which is in part locality dependent). Ordinarily, citizens do not think much about garbage unless, of course, a collector's strike finds them with a surplus of this commodity. The average citizen's concern with garbage ends at the curb. A nationwide survey of metropolitan housewives revealed that over 30 percent of them did not have any idea what happened to their solid waste after it was collected.

TABLE 2-6
SOCIAL AND POLITICAL FACTORS

Encouraging	Discouraging
1. Energy and resource shortages as a solution to solid waste disposal	1. Citizen attitude toward solid waste problem--noncrisis.
2. Concern on part of some citizens regarding limited resources	2. Maintenance of political stability
3. Pressure from environmental groups	3. Lack of comprehensive planning in selection
	4. Resistance to change in lifestyle, source separation, separate collection, disposal bottles, changes in convenience packaging
	5. Reluctance to pay increased costs of alternate disposal systems

Although most citizens now believe that we do have an energy shortage--few are aware that technology exists to recover energy from their own garbage. Wider dissemination of this information could be expected to encourage energy recovery from refuse if the economics of such a procedure are competitive with current practices. Possibly, local environmental groups might serve as a means to disseminate this information. However, any innovative system could be expected to encounter opposition if it poses the threat of additional cost or a change in lifestyle (e.g. source separation, changes in convenience packaging).

Municipal refuse is usually a low priority item with local decision makers; their main concern is also the short-term problem of collection and disposal. In most cities, collection alone is a big enough job. Local officials frequently do not have the time, funding, or manpower for long-range planning unless a local disposal crisis exists. In addition, unless a crisis exists, any change from existing disposal methods may present an immediate political liability to elected officials.

Although insufficient information exists to generalize about local decision makers' attitudes toward energy and resource recovery from refuse, we have found that local decision makers and waste managers do demand certain requirements of any waste-disposal system. First, and most important, a disposal system must be reliable and of proven technology. Unproven processes could only be expected to be implemented as pilot plants in areas with acute disposal problems, and then only as supplements to existing methods. Second, any disposal method (including energy recovery systems) must not cost substantially more than current practices.

Environmental:

The environmental factors which encourage or discourage energy and resource recovery are summarized in Table 2-7. Environmental constraints in the form of Federal, state, and local regulations provide a significant and immediate motivating force to clean up our environment. The underlying rationale for most environmental legislation has been a concern for public health. Environmental regulations seek to minimize or eliminate the potential health hazards that have been directly attributed to pollution.

Many past and some current waste disposal practices such as open dumps, open burning, and "unsanitary" sanitary landfills have made significant contributions to air and water pollution. Present and pending regulations and restrictions of these methods, as well as air and water quality standards, all demand change from "dirty" waste disposal practices for municipalities and industrial concerns. The legal constraints to clean up our environment and the realization of a real energy shortage are expected to be factors which will encourage the development and implementation of processes to recover energy from solid waste. Any proposed installation to recover energy from solid waste will have to meet the same state and Federal air and water quality standards for emissions as any other industrial plant. If the energy generating process represents a hybrid between conventional systems and new "energy from refuse technology" it may be subject to additional or unique combinations of existing regulations.

TABLE 2-7
ENVIRONMENTAL FACTORS

Encouraging	Discouraging
1. Present Restrictions on landfills	1. Lack of enforcement of present air, water, landfill standards
2. Ocean dumping restrictions-present and pending	2. Citizen attitude of unlimited resources
3. Air and water standards-present and pending	3. Public ignorance of environmental problems
4. Limited nature of resources	
5. Potential public health hazards of current practices	

Legal:

The legal factors which encourage or discourage energy and resource recovery are summarized in Table 2-8. Among the legal considerations which an energy recovery plant should consider are the problems associated with the ownership, marketing, and freight rates of recycled resources. The economic viability of most proposed processes depends on the extraction of at least some secondary materials. In fact, it may be the credits for these recycled goods that will make an energy recovery system competitive with current waste disposal practices.

Federal interest in energy and resource recovery dates back to the enactment of the Solid Waste Disposal Act of 1965, as amended by the Resource Recovery Act of 1970. These laws established as national goals the development of better technology for the recovery of secondary materials and energy from solid waste. More importantly, they provide Federal funding for demonstration grants and implement preferential Federal procurement policies for some goods manufactured from recycled resources.

TABLE 2-8
LEGAL FACTORS

Encouraging	Discouraging
1. Federal demonstration grants	1. Federal freight rate policies
2. Federal procurement policies	2. Natural gas regulations
3. Federal considerations for policy changes in: A. Freight rates B. Tax policies C. Tax status of bonds D. Product design legis.	3. Federal tax policies
	4. Tax free status of municipal bonds used in public/private systems
	5. Metropolitan area wide disposal systems needed for efficient operation
	6. Short term municipal contracts
	7. Exclusive franchises
	8. Product liability as an unknown
	9. Lack of product design legislation to alter composition of solid waste and encourage resource recovery

Federal freight rate policies have long been known to discriminate against certain categories of recycled material with respect to virgin materials. These policies are currently under review by the ICC, and those found to discriminate against recycled materials will be considered for change.

The secondary materials industry has begun to lobby for more equitable policies in the areas of depletion allowances and special capital gains treatment which have long been extended to producers of certain nonrenewable virgin resources. Policy changes advantageous to the secondary materials industry in both of these areas of major concern, would be expected to stimulate indirectly the implementation of more energy recovery from refuse.

On the other hand, there are a number of Federal governmental factors which tend to discourage energy and resource recovery. The Federally fixed price of interstate natural gas may force any refuse-derived fuel to compete at an unnaturally low price. (State and local fuel price setting may also have this same affect). Federal tax policies which give advantages to virgin raw materials over recycled raw materials will also have a detrimental effect if not changed.

A recent ruling by the Internal Revenue Service that interest from municipal bonds used by public/private partnership systems are not income tax free may make financing of proposed installations more difficult. A number of local policies and laws also discourage energy and resource recovery. Among them are the following:

1. The need to create area-wide disposal authority systems in order to supply the 453 metric ton per day of refuse required for efficient and economically practical energy recovery systems.

2. Short-term contract limitations (usually 5 years) imposed by many city charters may prevent the long-term arrangements required by many industries.

3. Exclusive franchises already granted by municipalities which may hamper the sale of recovered resources.

4. Unknown legal status of product liability for products produced from refuse may hamper the sales of these products to industry.

Table 2-9 summarizes our judgment as to the status of various disposal systems with respect to the more important variables which municipal decision makers must consider in accessing any disposal system.

2.8 RECOMMENDATIONS

To encourage resource and energy recovery from solid waste, we offer the following recommendations for change in existing policies.

1. Eliminate tax and freight rate advantages presently given virgin materials in order to make secondary materials more competitive and help conserve limited natural resources.

2. Subsidize research on resource recovery from solid waste.

3. Impose an excise tax on all virgin resources used to encourage use of secondary materials.

4. Implement governmental standards on product design and product reliability of products.

5. Adopt deposit (Oregon) legislation for the beverage industry.

6. Establish disposability standards for products. All products produced should have a disposal method. For certain products (e.g. automobiles, domestic appliances) it may be necessary to set disposal taxes or bonds which would be included in the original retail price of the product.

7. Provide Federal grants-in-aid to communities to help establish solid waste management systems.

8. Implement all present environmental standards relating to air, water, and landfills. Implementation of these standards would encourage the adoption of energy and resource recovery systems.

TABLE 2-9
SUMMARY OF LEGAL, ENVIRONMENTAL, POLITICAL, SOCIAL, AND ECONOMIC FACTORS

AVAILABLE DISPOSAL SOLUTIONS	LEGAL	ENVIRONMENTIALLY SOUND	POLITICALLY ACCEPTABLE	SOCIALLY ACCEPTABLE	ECONOMICAL	CURRENT TECHNICAL RELIABILITY
OPEN DUMPING	NO	NO	NO	NO	YES	HIGH
OPEN BURNING	NO	NO	NO	NO	YES	HIGH
OCEAN DUMPING	By permit only	NO	NO	NO	YES	HIGH
"DIRTY" INCINERATION	NO	NO	NO	NO	YES	HIGH
POLLUTION-FREE INCINERATION	YES	YES	?	YES	NO	MEDIUM
SANITARY LANDFILLS	YES	May not be soon.	Not in many areas.	Many problems in site selection.	Yes, in most areas.	HIGH
RESOURCE RECOVERY	Yes with* reservations	YES	Yes with reservations	Yes, with low costs	?	?
BIODEGRADATION-COMPOSTING	Yes with* reservations	YES	Site selection problems	No, if odor problem	?	?
ENERGY RECOVERY	Yes with* reservations	YES	Only when economical	Yes, with site selection problem	?	?
SOURCE SEPARATION AND/OR SEPARATE COLLECTIONS	Yes with** reservations	YES	No, potential campaign issue	No lifestyle changes are necessary	YES	Volume recovered not reliable

*Before any resource or energy recovery system can become economically competitive with virgin materials industries, a number of Federal Laws regulating freight rates and tax advantages must be changed. With solid fuel supplements for use in steam-fired generators a decision is needed regarding new versus old facilities from the EPA.

**Legal questions over who owns the resources separated at source: private haulers or city government.

SELECTED REFERENCES

2- 1 Bancroft, R.: America's Mayors and Councilmen: Their Problems and Frustrations. Nation's Cities, April, 1974, pp. 14-23.

2- 2 Michich, A.; Klee, A.; and Britton, P.: National Survey of Solid Waste Practice. Public Health Service Publication No. 1867, U. S. Dept. of H.E.W.

2- 3 Brunner, D. R.; and Keller, D. J.: Sanitary Landfill Design and Operation. (SW-65ts), EPA, 1972.

2- 4 Illinois Report Probes Citizen's Attitudes on Refuse Problems. Solid Waste Management, Feb., 1974, pp. 19t.

2- 5 Staff of National Analysts, Inc.: Housewives Attitudes Toward Solid Waste Disposal. EPA-R5-72-003.

2- 6 Hanks, T. G.: Solid Waste/Disease Relationship; A Literature Survey. Public Health Service Publications No. 999-UIH-6, 1967.

2- 7 Boggs, J. C.: Resource Recovery: The Now Dimensions in Solid Waste Management for the 1970's. Paper presented at National Industrial Solid Wastes Management Conference, University of Houston and Bureau of Solid Waste Management, March 24-26, 1970.

2- 8 Staff of the NRG NuFuel Co.: Sanitary Landfill Methane Recovery Program. Company brochure, 1974.

2- 9 Schneider, W. J.: Hydrologic Implications of Solid-Waste Disposal. U.S.G.S. Circular 601-F, 1970.

2-10 Hughes, G. M.; Landon, R. A.; and Faruolden, R. N.: Hydrogeology of Solid Waste Disposal Sites in Northeastern Illinois. (SW-12d), EPA, 1971.

2-11 DeGeare, T.: The New EPA Sanitary Landfill Guidelines. A paper in: Sanitary Landfilling Conference, compiled by J. E. Delaney, (SW-5p), EPA, 1973, pp. 76-80.

2-12 Staff of EPA: Report to Congress, Disposal of Hazardous Wastes. (SW-115), Washington, D.C., 1974.

2-13 Fungaroli, A. A.: Pollution of Subsurface Water by Sanitary Landfills. Vol. 1. (SW-12 rg), EPA, 1971.

2-14 Brown, L. F., Jr.; Fisher, W. L.; and Molina, J. F., Jr.: Evaluation of Sanitary Landfill Sites. Texas Coastal Zone--Geologic and Engineering Criteria. Geological Circular 72-3, Bureau of Economic Geology, The University of Texas at Austin, 1972.

2-15 Rail Transport of Solid Waste. Appendix B - Background Information: Control Measures for Public Health and Environmental Control. NTIS-PB-222 709, pp. 126-143.

2-16 Kenahan, C. B. et al: Composition and Characteristics of Municipal Incinerator Residues. U. S. Bureau of Mines, R. I. 7204, 1968.

2-17 Smith, D. D.; and Brown, R. P.: An Inventory of Marine Disposal of Solid Wastes. Proc. of National Industrial Solid Wastes Management Conference, University of Houston and Bureau of Solid Waste Management, March 24-26, 1970.

2-18 Gunnerson, C. G.: An Appraisal of Marine Disposal of Solid Wastes off the West Coast: A Preliminary Review and Results of a Survey. Paper presented at the 15th annual meeting of the Institute of Environmental Sciences (Anaheim, Calif.) April 23, 1969, reprinted and distributed by EPA.

2-19 Cities and the Nation's Disposal Crisis. Paper presented at the United States Conference of Mayors, National League of Cities, March, 1973.

2-20 Casey, Bob: Recent Trends in National Legislation--For the Total Protection of the Environment. Proc. of National Industrial Solid Wastes Management Conference. University of Houston and Bureau of Solid Waste Management, March 24-26, 1970, pp. 458-461.

2-21 VanVoorhis, F. S.: Environmental Issues and the Communications Gap. Resource Recovery, vol. 1, no. 2 April/May/June, 1974. pp. 26-29.

2-22 Darnay, A.: Keynote address at International Waste Equipment of Technology Exposition, National Solid Wastes Management Assn. (Houston, Texas) June 25, 1974.

2-23 Baum, B; and Parker, C. H.: Plastics Waste Disposal Practices in Landfill, Incineration, Pyrolysis, and Recycle. DeBell & Richardson, Inc., Prepared for Manufacturing Chemists Association (Washington, D.C.) 1972.

2-24 Rosenbaum, C.: U. E. Trash Pilot Plant Triples Air Dirt in Tests. St. Louis Post-Dispatch, March 18, 1974, Section 1-12B.

2-25 Glysson, E. A.; Schleyer, C. A.; and Leonard, D.: The Microbiological Quality of the Air in an Incinerator Environment. Paper in Resource Recovery thru Incineration, Proc. of 1974 National Incinerator Conference, ASME (New York), May 12-15, 1974, pp. 87-98.

2-26 Alvarez, R. J.: OSHA and Its Implications for Incinerator Plants. Paper in Resource Recovery thru Incineration, Proc. of 1974 National Incinerator Conference, ASME (New York), May 12-15, 1974, pp. 99-108.

2-27 Staff of Environmental Protection Agency: Second Report to Congress, Resource Recovery and Source Reduction. (SW-122), Washington, D. C., 1974.

2-28 Section 1(b), Natural Gas Act, 1938, as amended.

2-29 FPC vs Florida Power & Light Co. 404 U.S. 453, Jan. 12, 1972.

2-30 Section 208 of the Solid Waste Disposal Act, 1973, as amended.

2-31 Senate Bills 3549 and 3560, 93rd Congress.

2-32 Staff of Advisory Commission on Intergovernmental Relations: Regional Decision Making; New Strategies for Substate Districts. Vol. 1, A-43, 1974.

2-33 Solid Waste Management Law County of Monroe, State of New York, Motion No. 47 of 1973, Effective Aug. 17, 1973.

2-34 Monroe Livingston Sanitary Landfill, Inc., et al, v/s County of Monroe, State of New York, New York State Supreme Court, 1974.

2-35 Brown, S. M., Jr.: Advanced Planning Critical in Establishing Effective Land Use Management. Solid Waste Management, May, 1974, pp. 62-66.

2-36 Morck, C. W., Jr.: Legal Liabilities for Contract Waste Disposal. Paper in Resource Recovery thru Incineration, Proc. of 1974 National Incinerator Conference, ASME (New York), May 12-15, 1974, pp. 237-243.

2-37 Pettigrew, R. J.; et. al.: Rubber Reuse and Solid Waste Management. Contract Report to EPA (Washington, D. C.), 1971.

2-38 Smerglia, J. M.: Address before 1973 Annual Meeting, ASME (Detroit), Nov. 14, 1973.

2-39 Darnay, A.; and Franklin, W. E.: Salvage Markets for Materials in Solid Wastes. Midwest Research Inst., 1972. (Condensation prepared by EPA as publ. no. SW-29 c.1 in 1973.)

2-40 Bingham, T. H.; and Mulligan, P. R.: The Beverage Container Problem; Analysis and Recommendations. USGPO (Washington, D. C.), 1972.

2-41 McFarland, J. M.; Brink, D. L.; Glassey, C. R.; Klein, S. A.; McGauhey, P. H.; and Golueke, C. G.: Comprehensive Studies of Solid Wastes Managements. SERL Report No. 72-3, College of Engineering and School of Public Health, Univ. of Calif. Berkely, 1972.

2-42 Claussen, E. L.: Environmental Impacts of Packaging. No. 332, EPA, 1973.

2-43 Claussen, E. L.: Oregon's Bottle Bill: The First Six Months. No. 325, EPA, 1973.

2-44 Staff of EPA: Pesticides and Containers; Acceptance, Disposal, and Storage--Proposed Rulemaking and Issuance of Procedures. Federal Register, Vol. 38, no. 99, Part II (Washington, D. C.), May 23, 1973, pp. 13622-13626.

2-45 Heimburg, R. W.: Environmental Effects of the Incineration of Plastics. In Chemical Engineering Applications in Solid Waste Treatment, Guy E. Weismantel, ed. A.I.Ch.E. Symposium Series 122, vol. 68, 1972, pp. 21-27.

2-46 Boettner, E. A.; and Ball, G. L.: Combustion Products of Plastics and their Contribution to Incinerator Problems. Chemical Engineering Applications in Solid Waste Treatment, Guy E. Weismantel, ed., A.I.Ch.E. Symposium Series 122, vol. 68, 1972, pp. 13-20.

2-47 Stellman, J. M.; and Daum, S. M.: Work is Hazardous to Your Health. Vintage Books, 1973.

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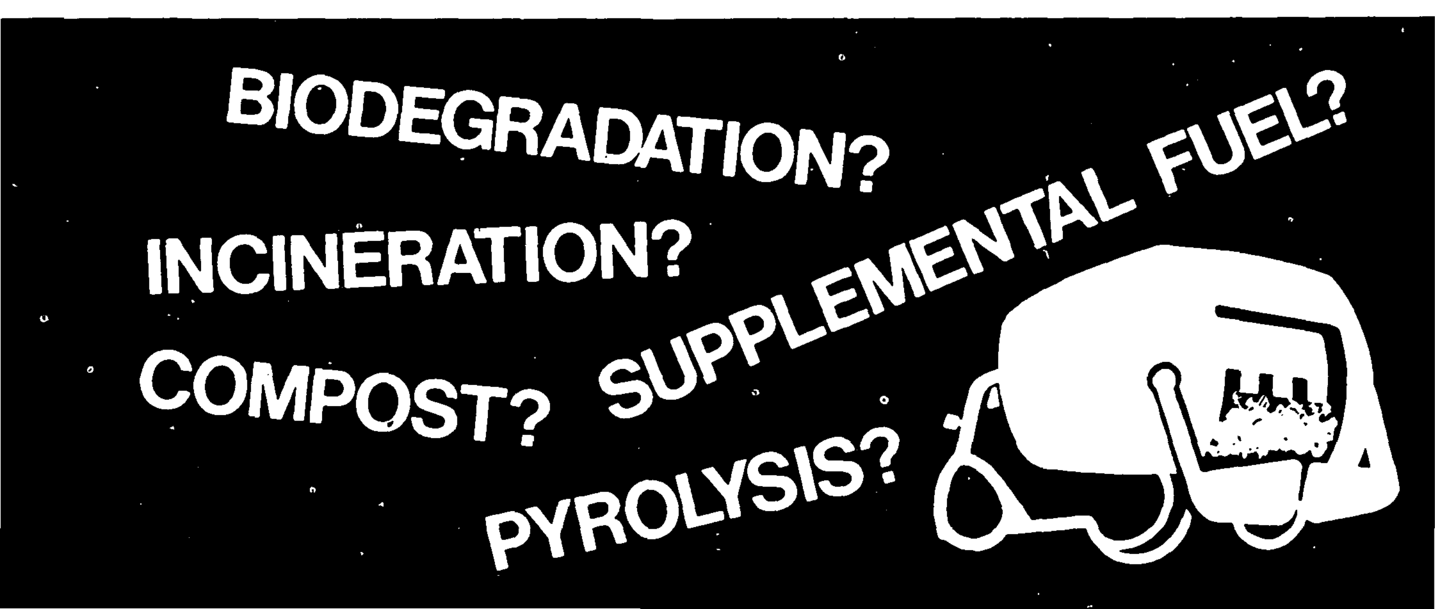
Chapter 3

Technical Aspects of Energy Recovery from Solid Waste

ENERGY RECOVERY FROM SOLID WASTE



3.1 INTRODUCTION

The use of solid waste as an energy source could provide a small percentage of this country's total energy demand. Based on an energy content of solid waste of approximately 1.165×10^7 joule/kilogram (5000 Btu/pound) the energy from solid waste could provide a fuel equivalent to 25 percent of our annual consumption of natural gas or about 2 percent of our current fossil fuel consumption (ref. 3-1). On a more local basis, the energy from a community's solid waste could be used to provide up to 20 percent of that community's electrical power requirements. Locally, the recovery of energy from solid waste appears to contribute a significant amount to the total energy picture, but for many communities, the energy recovery will be a secondary advantage. The primary advantage will be the virtual elimination of the solid waste disposal problem.

Energy recovery from solid waste is a relatively new concept, precipitated by the shortage of sanitary landfills in highly populated areas, by public concern over the location and presence of landfills, and to a lesser extent, by the recent energy crisis. The traditional disposal methods are shown schematically in Figure 3-1. The three methods shown are open dumping, sanitary landfill, and incineration. There are many disadvantages associated with each of these alternatives, and many of these have been discussed previously.

Not one of these methods is totally acceptable as a solution to the solid waste problem. Sanitary landfills are generally the cheapest means of disposing of the solid waste. Consequently, systems which recover energy from solid waste are often compared to sanitary landfill costs and will probably have to compete economically with landfill disposal methods to be considered by many communities. The following is a discussion of sanitary landfills and the economics of this waste disposal method. These data may be used for comparison with the costs of energy recovery systems discussed in later sections. Incineration costs are discussed in the Midwest Institute Report, (ref. 3-2), and will not be discussed in detail in this report.

3.1.1 Sanitary Landfill

Sanitary landfills receive the bulk of the refuse generated in this country. Close-in sites are usually the cheapest means of disposal of Mixed Municipal

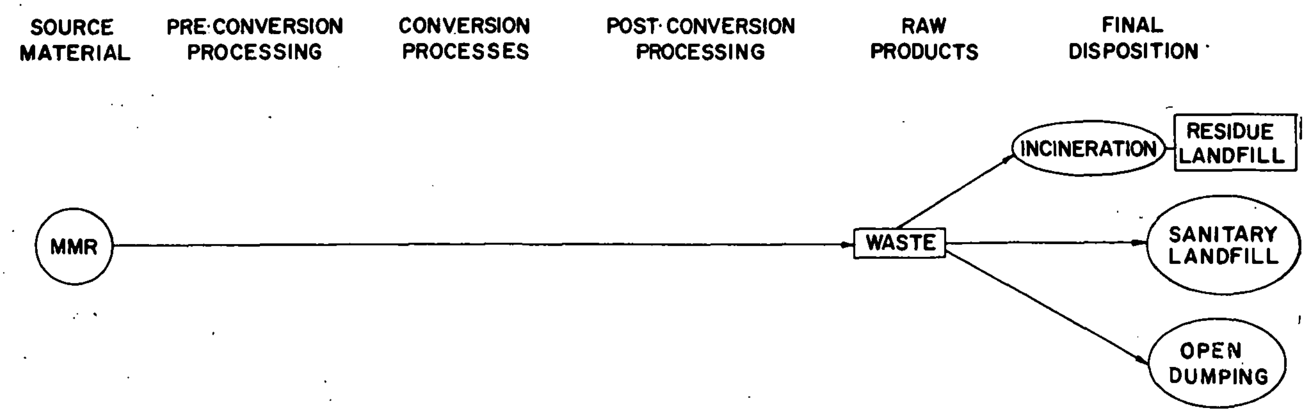


FIGURE 3-1
CONVENTIONAL METHODS OF REFUSE DISPOSAL

Refuse (MMR), but land is becoming less available for disposal sites in large metropolitan areas. This means that remote disposal areas must be found. Remote sites make the disposal cost of the MMR greater because of increased transportation and time. The economics of a close-in and a remote sanitary landfill are given in Tables 3-1 and 3-2 (ref. 3-2).

TABLE 3-1
TOTAL CAPITAL REQUIREMENTS FOR CLOSE-IN SANITARY LANDFILL
907 METRIC TON/DAY (1000 TON/DAY) RAW WASTE INPUT CAPACITY

Amortized Investment	
Engineering, R & D	$ 114,000
Startup	83,000
Total Amortized Investment	$ 197,000
Fixed Investment	
Site Improvements	$ 300,000
Structures	100,000
Equipment	350,000
Miscellaneous	200,000
Total Fixed Investment	$ 950,000
Recoverable Investment	
Land	$1,200,000
Working Capital	125,000
Total Recoverable Investment	$1,325,000
Total Capital Requirement	$2,472,000
Total Capital Requirement at:	
227 metric ton/day (250 ton/day) Capacity	$ 678,000
454 metric ton/day (500 ton/day) Capacity	$1,295,000
1814 metric ton/day (2000 ton/day) Capacity	$4,725,000

TABLE 3-2
TOTAL CAPITAL REQUIREMENTS FOR REMOTE SANITARY LANDFILL*
907 METRIC TON/DAY (1000 TON/DAY) RAW WASTE INPUT CAPACITY

Amortized Investment	
Engineering, R & D	$ 234,000
Startup	133,000
Total Amortized Investment	$ 367,000
Fixed Investment	
Site Improvements	$ 300,000
Structures	100,000
Equipment	350,000
Transfer Station	1,000,000
Miscellaneous	200,000
Total Fixed Investment	$1,950,000
Recoverable Investment	
Land	$ 300,000
Working Capital	200,000
Total Recoverable Investment	$ 500,000
Total Capital Requirement	$2,817,000
Total Capital Requirement at:	
227 metric ton/day (250 ton/day) Capacity	$ 772,000
454 metric ton/day (500 ton/day) Capacity	$1,475,000
1814 metric ton/day (2000 ton/day) Capacity	$5,380,000

*Landfill site located 100 miles from central refuse generation point.

It may be seen that the disposal costs associated with a sanitary landfill vary with the capacity. The disposal costs, however, range from $3.10/metric ton ($2.81/ton) for 227 metric ton/day (250 ton/day) capacity to $2.65/metric ton ($2.41/ton) for an 1814 metric ton/day (2000 ton/day) capacity, for the close-in disposal site.

The costs for the remote landfill are somewhat higher, ranging from $6.87/metric ton ($6.25/ton) to $6.25/metric ton ($5.67/ton), depending on the capacity. These cost estimates for sanitary landfill disposal are taken from reference 3-2, and may be considered typical costs. Local land, labor, and transportation costs could cause some deviation from these economic data.

3.1.2 Pre-Conversion Processing Routes

As an alternative to landfill or incineration of the raw refuse, some processing could be performed, either for the purpose of materials recovery or simply for the purpose of rendering the refuse more acceptable for sanitary landfill. If additional separation, drying, and grinding steps are performed, a solid fuel could be obtained. These various routes are shown in Figure 3-2.

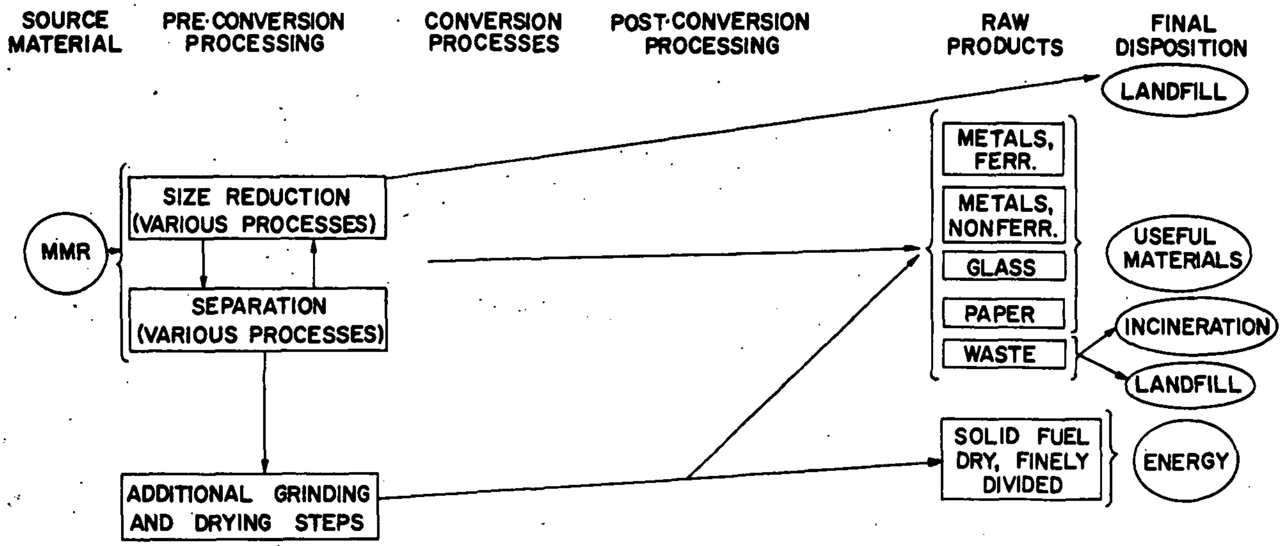


FIGURE 3-2
PRE-CONVERSION PROCESSING ROUTES

Resource recovery systems are front-end or pre-conversion process systems which will recover metals, glass, and other useful materials. After recovery, the remaining products in the MMR could either be landfilled or incinerated.

3.1.3 ENERGY CONVERSION ALTERNATIVES

If energy from refuse is desired, several conversion alternatives are available. The broad categories are:

1. incineration
2. pyrolysis
3. biodegradation

Each of these methods is discussed in the following sections.

3.1.3.1 INCINERATION WITH ENERGY RECOVERY

Incineration of refuse in this country, historically, has been plagued with problems. The incinerators polluted the atmosphere with gaseous and solid particulates, obnoxious odors, and unburned refuse; were expensive to operate; and were generally not accepted by the public. Only a relatively small number (less than 200) of municipal incinerators were still in operation in the U. S. in 1972 (ref. 3-1).

The newer incineration processes, with energy recovery, are better designed and should improve on all of the above negative characteristics of incinerators. Figure 3-3 is a schematic illustration of the possible incineration routes for energy recovery. In general, they are direct incineration of refuse alone, and the use of refuse as a supplemental fuel. Materials recovery can occur before or after the conversion process, depending on the resources desired. A number of products are possible from the incineration conversion process, the most important probably being steam.

3.1.3.2 PYROLYSIS

Pyrolysis is defined as destructive distillation, or thermal decomposition, without complete combustion. Figure 3-4 is a schematic illustration of pyrolysis conversion processes. Pyrolysis products may consist of storeable gaseous, liquid, or solid fuels, and resource recovery may occur before or after the conversion process, again depending on the resources desired.

3.1.3.3 BIODEGRADATION OF REFUSE

Biodegradation conversion routes are shown schematically in Figure 3-5. The two

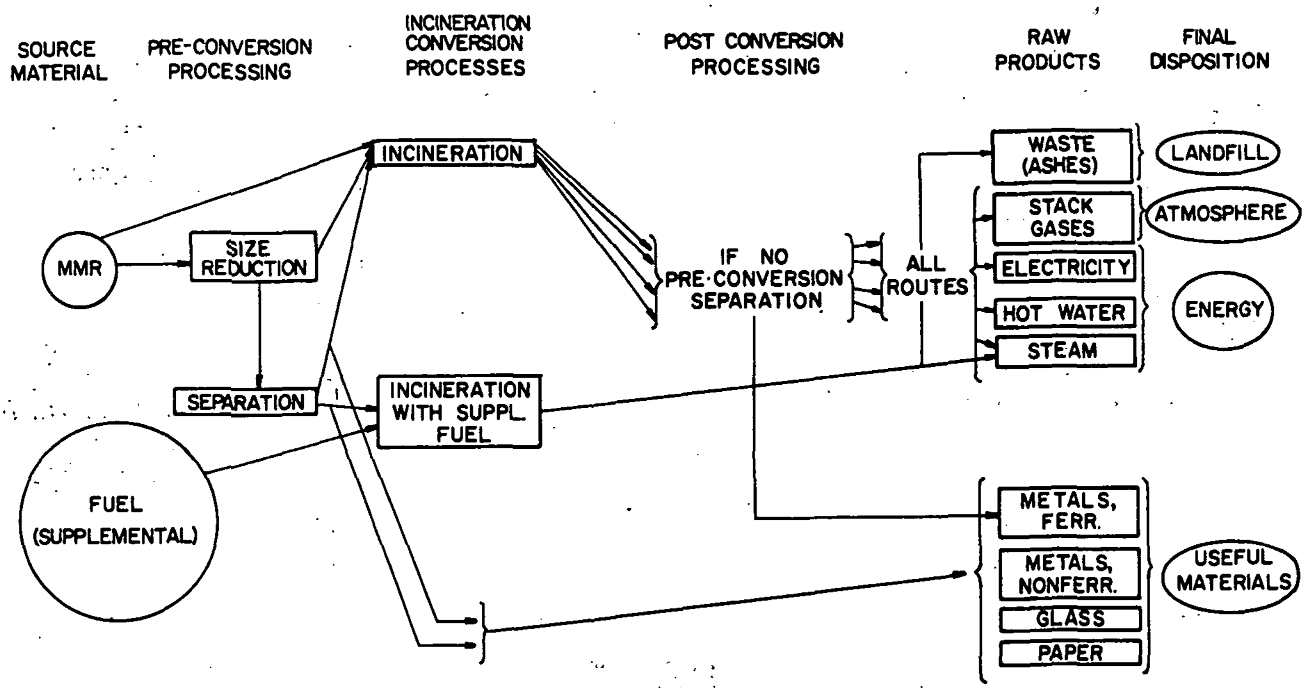


FIGURE 3-3
REFUSE INCINERATION ROUTES WITH ENERGY RECOVERY

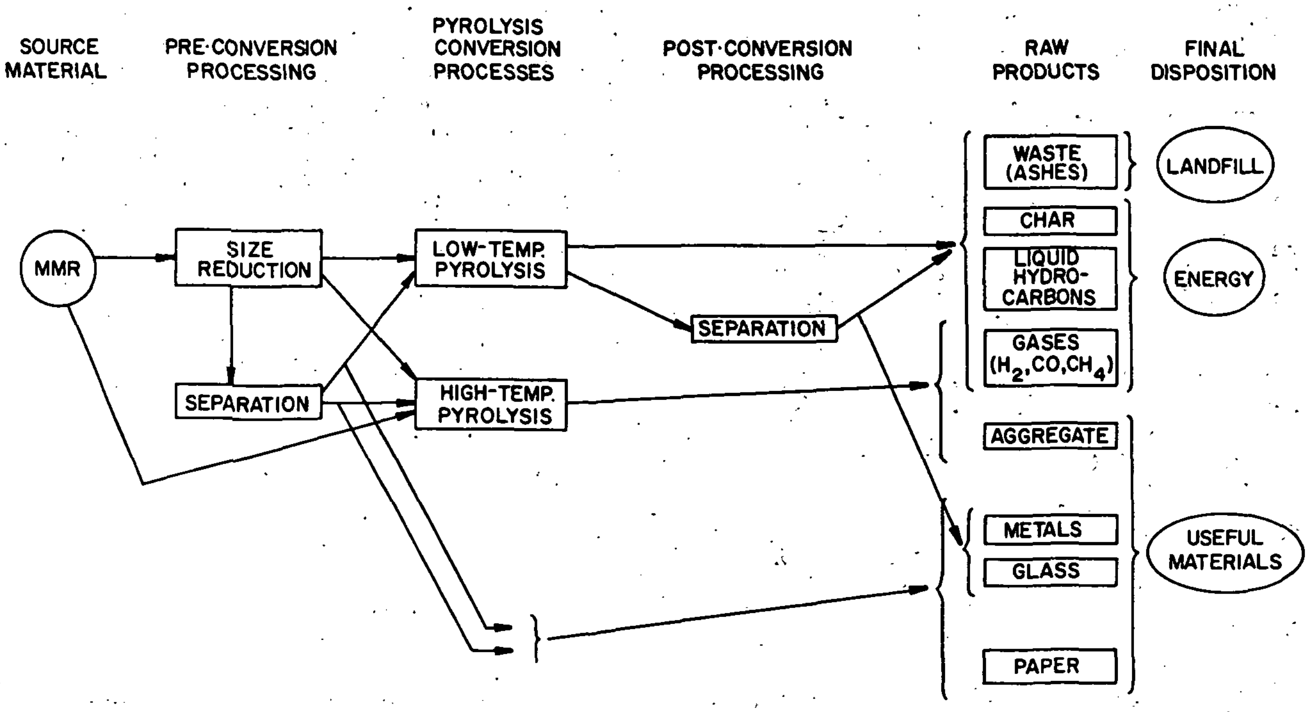


FIGURE 3-4
PYROLYSIS OF REFUSE

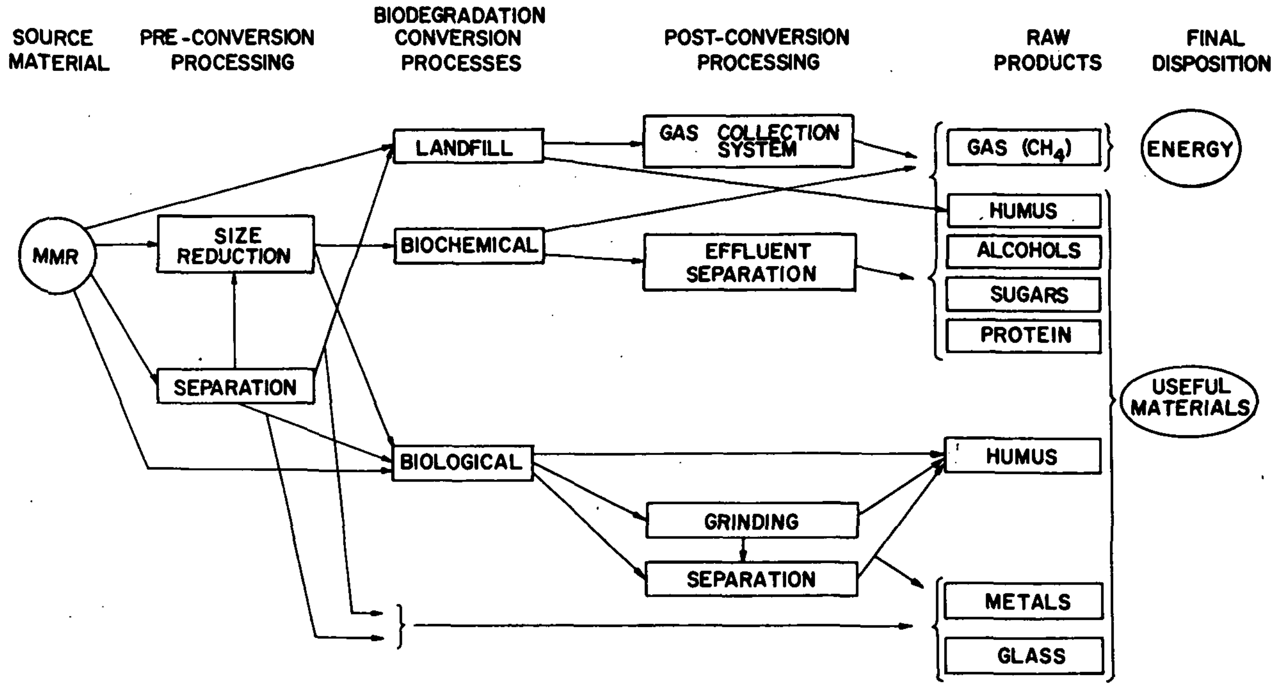


FIGURE 3-5
BIODEGRADATION OF REFUSE

broad categories are biochemical and biological conversion, and several products are possible, including gases, liquids, and solids.

3.1.4 Process Economic Data Sheets

A critical factor to be considered in the selection of any conversion process for energy recovery is the economic aspect of that system. A review of currently available information demonstrates the difficulty in obtaining reliable cost estimates for any of the energy recovery waste disposal methods. From a financial standpoint, the most important consideration to the consumer is how much it will cost to dispose of his solid waste; this cost can ultimately be translated into "dollars per ton". It should be pointed out that the technology of converting solid waste to usable energy is relatively new and currently there are few full production plants in operation in the United States. Hard financial figures are therefore available, and estimates which are given necessitate many assumptions which are discussed elsewhere in this report.

The methods of cost presentation used in the literature describing the disposal systems are almost as numerous as the number of different processes; therefore, it is difficult to make a uniform comparison of the debits and credits that are associated with each process. As a first step toward making uniform comparisons and to give the reader a better appreciation of the costs involved, Figures 3-6 and 3-7 have been developed which show the major components of the costs and credits for available options. These tables reflect the various sources of data, and no attempt has been made to verify the calculations, translate to a common year base, common city, or other factors which would alter the actual numbers.

Figure 3-6 will be used to compile the cost data in two major categories: 1) capital cost and 2) operating costs. Using this technique, all the costs which are primarily associated with the origination of the project are itemized under capital costs, while continuing costs which occur on an annual basis are itemized under operating costs. A comment column is provided to allow a limited explanation of the data to be given on the form itself.

It should be noted that all capital costs are "totals" and must be amortized or expensed before an economic study can properly be made.

The form shown in Figure 3-7 is used to collect information on the potential income generated by the sale of energy and resources recovered from solid waste. The comment column is provided to allow a

Process Name: ____________________

Data Source: ____________________

Capacity in Tons/Day: ____________________

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $) Land Preprocessing Eqmt Processing Eqmt Postprocessing Eqmt Utilities Building & Roads Site Preparation Engr. & R & D Plant Startup Working Capital Misc.: TOTAL		
OPERATING COSTS ($ PER YR) Maint. Material Maint. Labor Dir. Labor Dir. Materials Overhead Utilities Taxes Insurance Interest Disposal of Residue Payroll Benefits Fuel Misc.: TOTAL		
CREDITS ASSUMED ($ PER YR)		

FIGURE 3-6
PROCESS COST SHEET

limited explanation of the data to be given on the form itself. Space is provided in the left hand column of the form to introduce additional labels that more adequately describe a particular resource credit. The total income per year at the bottom of the form should be transferred to the last line of the Process Cost Sheet.

3.2 PRE-PROCESSING TECHNIQUES

3.2.1 General Considerations

Generally speaking, pre-processing includes all the steps of handling the Mixed Municipal Refuse (MMR) from its source up to the stage where it is ready for conversion processing. In this report, however, the collection aspects of MMR are not considered.

The content of MMR varies daily in a given location, and even varies in different localities of the country. Refuse generally contains some moisture, and the rainy season drastically increases the total refuse tonnage to be collected. Table 3-3 contains a "typical" composition of MMR, which may be used to determine the amount of potential resources that may be recovered from refuse (ref. 3-1).

Process Name: ____________________

Data Source: ____________________

Capacity in Tons/Day: ____________________

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals		
Nonmagnetic Metals		
Glass		
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)		

FIGURE 3-7
RESOURCE RECOVERY DATA SHEET

TABLE 3-3
TYPICAL COMPOSITION OF
MIXED MUNICIPAL REFUSE

Waste Component	Percent by Weight
Paper	33.0
Glass	8.0
Ferrous metals	7.6
Plastics, leather, rubber, textiles, wood	6.4
Garbage and yard wastes	15.6
Miscellaneous (ash, dirt, etc.)	1.8
Total Dry Weight	73.0
Moisture	27.0
Total	100.0

It should be noted from Table 3-3 that the refuse typically contains a large amount of moisture. Thus the amount of resources actually present and recoverable, either in the form of materials or energy, is typically 70 to 80 percent of the as-received tonnage.

Pre-processing should include a truck scale to weigh the material received for processing. The equipment itself includes a concrete weighing platform, a weighing device, and a recording mechanism. Applicable accuracy and tolerance requirements can be found in the National Bureau of Standards Handbook H44. A 45 metric ton (50-ton) capacity truck scale is quite sufficient for the purpose. There are many manufacturing companies dealing in truck scales on the market. The approximate cost of installing such a unit may be about $38,000. The services of one person is sufficient to operate the scale and to maintain the records.

3.2.2 Size Reduction Techniques

The use of size reduction equipment (i.e. hammermills, shredders, grinders, etc.) is gaining acceptance as a preliminary operation in processing solid waste. Two decades of experience and published data concerning the characteristics of shredded refuse are emerging because of the changing economic picture and environmental concerns associated with traditional solid waste disposal philosophy.

Benefits of shredding can be realized by almost any kind of follow up process whether it is energy recovery, material recovery, or landfill. Initially, shredding of refuse was used as an attempt to increase combustion efficiencies for incineration processes and for the purpose of composting wastes. Although incineration and composting have only obtained limited success (to be discussed in later sections of this report) the following advantages of shredding have been noted as a result of these operations:

1. volume of refuse is reduced by about 50 percent,
2. refuse is more predictable and homogeneous,
3. refuse is more rapidly stabilized,
4. conveyor movement, magnetic separation, and air classification operations are enhanced,
5. danger from explosives reaching later processes is virtually eliminated,
6. reduces scavenger population (rat, gulls, etc.) at landfill sites,
7. eliminates obnoxious odors usually encountered at dumps,
8. provides more surface area for thermal processes such as pyrolysis or incineration,
9. shredded nonrecognizable waste is considered more acceptable for land disposal,
10. blowing debris is less of a problem because of the dense interlocking characteristics of shredded trash, and,
11. fire potential, a definite problem with landfill, is substantially reduced.

Since there are definite benefits that result from size reduction operations, it would be helpful to consider the various kinds of size reduction equipment.

3.2.2.1 SHREDDERS

The term "shredder" will be used in this report to describe such equipment as: pulverizers, hammermills, crushers, shredders, etc. These kinds of equipment represent more than 90 percent of the size reduction equipment in operation processing municipal refuse. To further illustrate the kinds of equipment categorized as shredders, a list of manufacturers is presented in the appendix.

Size reduction operations on mixed municipal refuse are carried on in 25 states (ref. 3-3). Considerable amounts of data are available on shredding costs, maintenance, and characteristics of shredded refuse. Table 3-4 lists shredding operations in the United States that handle mixed municipal refuse.

TABLE 3-4
SOLID WASTE SHREDDING OPERATIONS (REF. 3-3)

Location	Metric Ton/Hr Capacity	Ton/Hour Capacity	Began	Shredder Shaft Type
Los Gatos, Calif.	27	30	1969	Horizontal
Menlo Park, Calif.	3	3	1973	Vertical
Mountainview, Calif.	14	15	1974	Vertical
San Diego, Calif.	36	40	1970	Horizontal
Alamosa, Colo.	14	15	1972	Vertical
Chaffee County, Colo.	14	15	1974	Vertical
Pueblo, Colo.	36	40	1974	Vertical
Milford, Conn.	45	50	1972	Vertical
New Britain, Conn.	45	50	1975	Horizontal
New London, Conn.	72	80	1972	Horizontal
New Castle, Del.	90	100	1972	Horizontal
Pompano Beach, Fla.	14	15	1972	Vertical
Atlanta, Geo.	67	75	1975	Horizontal
DeKalb County, Geo.	45	50	1973	Vertical
Chicago, Ill.	72	80	1970	Horizontal
Chicago, Ill.	27	30	1971	Horizontal
Chicago, Ill.	67	75	1975	Horizontal
Pleasant Hill, Iowa	18	20	1973	Horizontal
Baltimore, Md.	45	50	1974	Horizontal
Marlboro, Mass.	27	30	1973	Horizontal
St. Louis, Mo.	67	75	1971	Horizontal
Great Falls, Mont.	31	35	1973	Vertical
Monmouth County, N. J.	45	50	1974	Vertical
Elmira, N. Y.	36	40	1973	Horizontal
New York, N. Y.	36	40	1969	Horizontal
Guilford County, N. C.	45	50	1974	Vertical
Columbus, Ohio	54	60	1974	Horizontal
Willoughby, Ohio	22	25	1975	Vertical
Portland, Oreg.	18	20	1973	Horizontal
Altoona, Pa.	14	15	1966	Horizontal
Harrisburg, Pa.	72	80	1970	Horizontal

TABLE 3-4 (CONTINUED)

Location	Metric Ton/Hr Capacity	Ton/Hour Capacity	Began	Shredder Shaft Type
LeHigh County, Pa.	36	40	1974	Vertical
Providence, R. I.	45	50	1972	Vertical
Charleston, S. C.	72	80	1974	Vertical
Georgetown, S. C.	18	20	1974	Vertical
Williamsburg, S. C.	18	20	1973	Vertical
Galveston, Tex.	22	25	1973	Vertical
Houston, Tex.	36	40	1965	Horizontal
Norfolk, Va.	27	30	1974	Horizontal
Cowlitz County, Wash.	45	50	1975	Horizontal
Longview, Wash.	45	50	1971	Horizontal
Appleton, Wis.	45	50	1974	Horizontal
Racine, Wis.	22	24	1958	Horizontal
Madison, Wis.	22	25	1967	Horizontal & Vertical

3.2.2.2 PRIMARY SHREDDERS

The first size reduction operation performed on mixed municipal refuse is referred to as primary shredding. Past experience with primary shredders have resulted in observations such as: reliability has been low, maintenance is expensive and time consuming, and reliability has been low. These observations, however, have to be put in proper perspective.

First, shredding mixed refuse should never be expected to be accomplished without substantial costs and routine maintenance. To sustain impact conditions necessary to sever (or crush) articles ranging from paper, plastics, and fabrics to metal, rubber, and construction debris, requires high power consumption. Cutting or impact edges will have to be routinely replaced or rebuilt which requires a regular maintenance program. Three types of primary shredders are considered in this report: (1) vertical shaft shredders, (2) horizontal shaft shredders, and (3) flail mills.

Flail mills are being evaluated as a process to liberate items in MMR without appreciable size reduction. A flail mill would allow the recovery of magnetic items (by magnetic separation after the flail mill) and thereby reduce the difficulty and cost of secondary shredding.

The multi-jointed arms of a flail mill will self relieve and allow hard objects to pass through without rework. Since a flail mill passes all input materials quickly without repeated impacts, the capital costs, the maintenance costs, and the operating costs are less than for primary shredders. In addition, a more uniform impacting situation permits operation at maximum capacity without large variations in load.

The disadvantages of a flail mill are primarily centered around the fact that it is a new concept as applied to MMR. The flail mill along with classification equipment and secondary shredders will have to be evaluated in full scale operation.

Vertical and horizontal shaft primary shredders that process MMR can be characterized as hammermills (see Figures 3-8 and 3-9). Both types reduce the size of

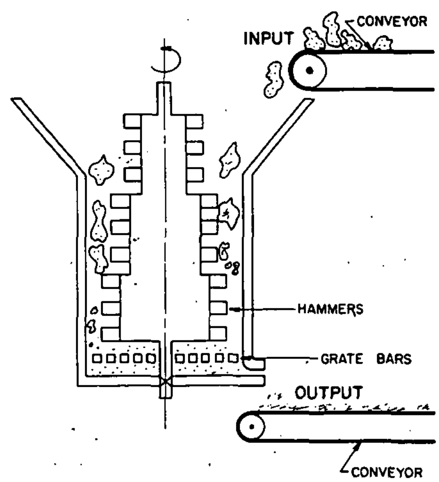


FIGURE 3-8
VERTICAL SHAFT HAMMERMILL

the input MMR to a uniform and relatively homogenous output product. The basic differences between vertical and horizontal shaft hammermills are:

1. A vertical shaft unit must reduce all objects to a size which can be discharged through grates resulting in a more uniform and homogenous product.

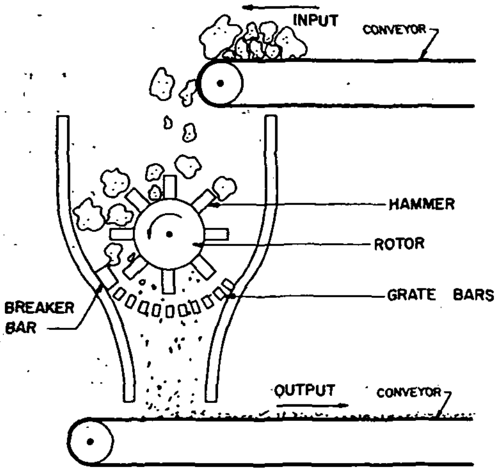


FIGURE 3-9
HORIZONTAL SHAFT HAMMERMILL

2. A horizontal shaft hammermill can more easily reject objects that are not easily shredded.

Performance data for primary shredders can be found in the literature in ref. 3-4, 3-5, 3-6, 3-7, and Figure 3-10 indicates

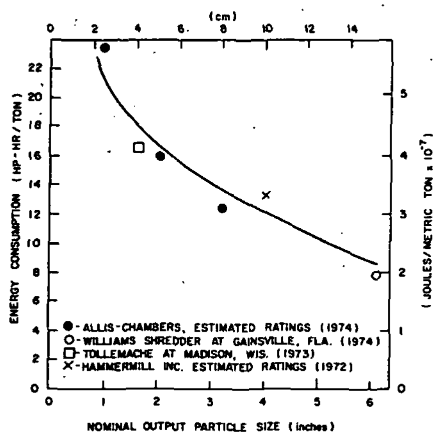


FIGURE 3-10
PRIMARY SHREDDING ENERGY CONSUMPTION
FOR MIXED MUNICIPAL REFUSE

the energy requirements for size reduction operations on solid wastes. The exponential increase in energy required for smaller particle output size is expected for hammermills of comparable capacities. The units shown represent a capacity to handle 30 metric tons per hour.

Cost data for shredding facilities that receive MMR and process it to a nominal output particle size of 2.5 centimeters are available for both horizontal and vertical hammermills (ref. 3-4 and 3-5). Two facilities, Madison, Wisconsin and Gainesville, Florida, report that if the complete plant is amortized (the administrative cost included), the total size reduction operation would cost approximately $4.41 per metric ton of refuse processed. This does not include the disposal cost for the shredded refuse.

3.2.2.3 SECONDARY SHREDDERS

Secondary shredders consist of equipment such as wet pulpers, disk mills, pulverizers, grinders, hammermills, and cage disintegrators. The task of secondary shredding also employs a tearing, impacting, or pulverizing action. Again, it should be expected (and not underestimated) that frequent hammer or cutting edge maintenance is required. Electrical power requirements will be high to sustain impacting conditions; however, the more uniform product as received from the primary shredder should reduce the electrical power overload conditions that frequently occur in primary shredding. Some of the equipment most frequently used in secondary shredding operations are shown in Figures 3-11, 3-12, 3-13, and 3-14 (ref. 3-8).

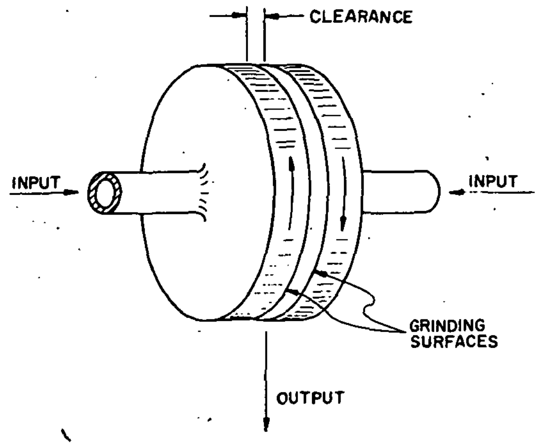


FIGURE 3-11
DISK MILL SCHEMATIC

Disk mills are high speed machines consisting of disks that rotate in opposite directions. Refuse, processed by a primary shredder so that the particle size is less than 5 centimeters, is fed axially into the disk mill and is reduced in size to a fine particle. The output particle size is controlled by the clearance between disks. Pulpable materials are most easily processed by disk mills and separation operations prior to this type of mill would be necessary.

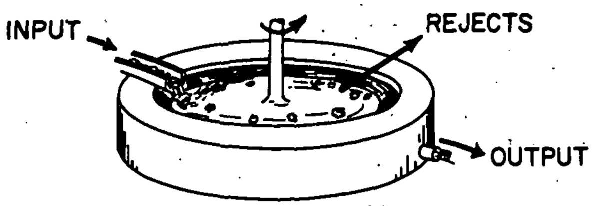


FIGURE 3-12
WET PULPER SCHEMATIC

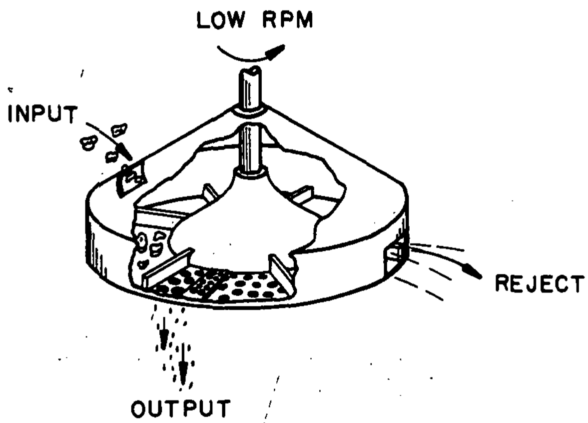


FIGURE 3-13
SCHEMATIC OF RASP MILL

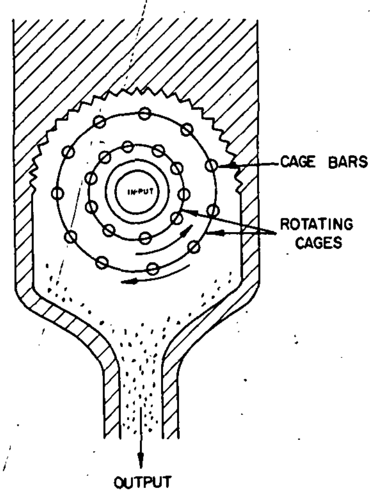


FIGURE 3-14
CAGE DISINTEGRATOR SCHEMATIC

Rasp mills are massive machines that usually run at speeds less than 10 RPM. The input to a rasp mill requires very little (if any) separation since items that resist this size reduction operation can be rejected easily. The output product from a rasp mill is usually larger than 3 centimeters.

Cage disintegrators have multiple cages that rotate in opposite directions at high speeds. The output product can be reduced to 1 centimeter or less (fine powders). Selective input is required for cage disintegrators, and friable materials are handled best.

3.2.3 Separation Techniques

One of the important steps in preparing MMR for any processing is segregation of the MMR according to its main component categories. In most cases an efficient separation process achieves most of the material recovery contemplated in the process. At present, many types of separation processes are in use in various industries. It is only a question of adopting these units for handling MMR. In the last few years many of the manufacturers have tried to adopt their products for this special use. The following are some of the major techniques of separation that are being practiced in the various types of industries:

- Hand sorting
- Screens
- Magnetic separators
- Air classifiers
- Optical sorting
- Inertial separation
- Eddy current separation
- High-density electrostatic separation
- Miscellaneous separation methods

3.2.3.1 HAND SORTING

Hand sorting is perhaps the most effective and least complicated separation process. It needs almost no equipment other than belt conveyors. The drawbacks are the human elements involved. Further, the soaring labor cost adds to these drawbacks making the process the least economical when large quantities of MMR are involved. Hand removal of bulky items from the belt conveyor is sometimes unavoidable, as bulky materials and rags clog the equipment and force shut downs. A report based on the operation of the Lone Star Organics, Inc., plant at Houston, Texas, states that one person can pick about .450 to .680 metric tons (0.5 to 0.75 tons) per hour of newsprint, cardboard, etc., from the mixed waste (ref. 3-8). This corresponds to 1.5 to 2.2

man-hours per metric ton and the separation cost may vary from $3.90 to $5.50 per metric ton depending on labor costs.

Another type of hand sorting that can be adopted is separation at the source. This is a very effective and economical method for material recovery, if there is cooperation from the public. The separation can be classified according to newsprint, glass bottles, and cans. As these materials have to be picked up separately, however, the cost of collection will increase. On the other hand, the volume of remaining refuse will be reduced considerably. The total economics of the operation depend on the market value of the recovered materials. The success of the program is limited to small educated communities close to the market of the recovered materials. These conclusions are to some extent confirmed by sample studies conducted by SCS Engineers of California under the sponsorship of EPA's Resources Recovery Division of the Office of the Solid Waste Management Programs (ref. 3-9 and 3-10).

3.2.3.2 SCREENING

In most processes, the physical dimensions and the size of feed inlet determine the size range of the feed material. Therefore, it is not only necessary to reduce the size of the MMR but also to separate it according to the sizes. This is best accomplished by screening. One process can eliminate both larger and smaller than the required range of size limitations. Screening is not new to the industrial manufacturers, and there are many types of screens available on the market. The vibrating rectangular or circular set of screens is most common. The agitation of material is maintained by mechanical vibration.

The capacity of screens vary from 9.8 metric ton/hour to 98 metric ton/hour per square meter (1 to 8 ton/hour per square foot) of screen area depending on the type of conventional mineral material. This does not include solid waste as one of the materials used in arriving at the above data. The lower values are for materials such as fertilizer and cake sizing. As solid waste is still more irregular and nonhomogenous, a lower value than 9.8 metric ton/hour per square meter may be assumed for purposes of designing the screen sizes. With MMR, clogging of the screen openings is a problem, especially if the refuse is wet. Reference 3-8 can be used to determine approximate screen sizes for different applications.

Rotating inclined cylindrical screens such as Trommel screens are sometimes used instead of vibrating flat screens. The tumbling action provides necessary agitation and self cleaning action for clogged openings of the screen. Trommel screens of 4.5 metric ton/hour (50 ton/hour) capacity cost approximately $8,000.

3.2.3.3 MAGNETIC SEPARATION

The separation of magnetic materials (primarily ferrous) from heterogenous industrial mixtures by magnetic separation is practiced quite widely. There are several companies who specialize in the manufacturing and marketing of such equipment with special application to MMR.

Efficient separation of magnetic materials from MMR depends on the degree of size reduction and to the extent the ferrous materials are physically separated from nonferrous materials. Figures 3-15 and 3-16 are schematic illustrations of

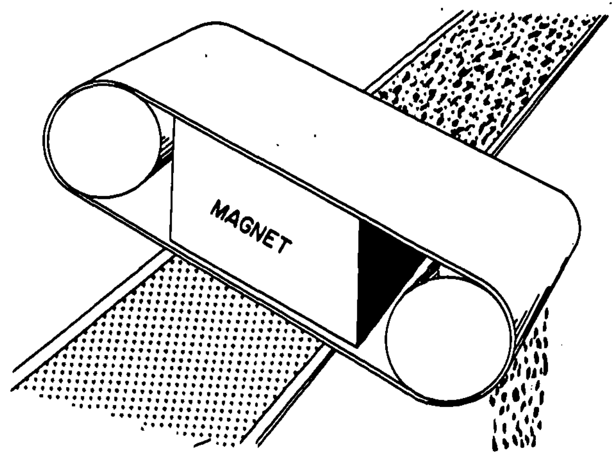


FIGURE 3-15
SUSPENDED-TYPE PERMANENT MAGNETIC SEPARATOR

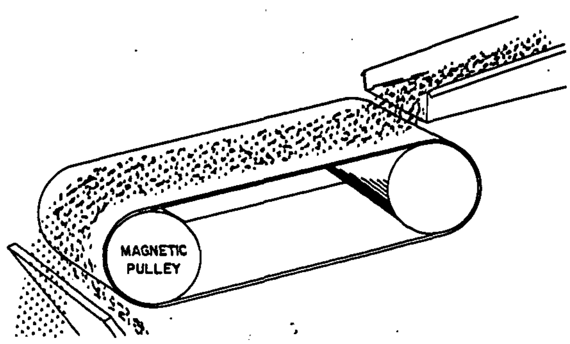


FIGURE 3-16
PULLEY-TYPE PERMANENT MAGNETIC SEPARATOR

magnetic separators. They can be made of either permanent magnets or electro-magnets. The graphs in Figures 3-17 and 3-18 illustrate the relationship of capital cost of magnetic separation as a function of capacity of the plant and belt width. Except at very low capacities, the cost is proportional to the capacity and is more economical at higher capacities.

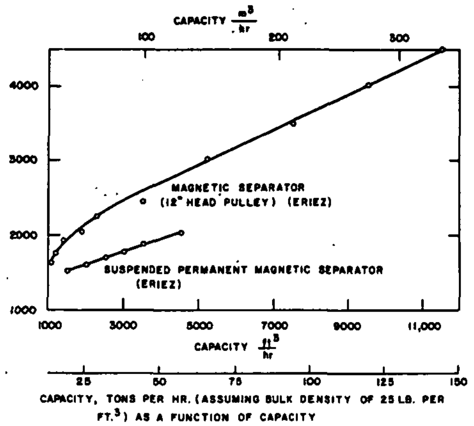


FIGURE 3-17
CAPITAL COST OF MAGNETIC SEPARATORS AS A FUNCTION OF CAPACITY

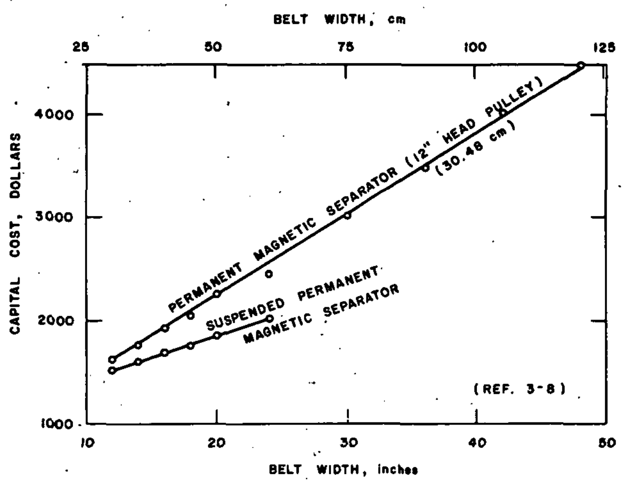


FIGURE 3-18
CAPITAL COST OF MAGNETIC SEPARATORS AS A FUNCTION OF BELT WIDTH

As belt width is always proportional to the capacity of the plant, the cost is also proportional to the belt width. Broader belts are more economical than narrow ones. These conclusions are based on data provided by the Eriez Manufacturing Company (Eriez Magnetics) in the report by N. L. Drobny and others (ref. 3-8). A magnetic separator system for a 54 metric ton/day (60 ton/day) plant will cost around $15,000 to $20,000.*

3.2.3.4 AIR CLASSIFICATION

In general terms, air classification can be described as classification of materials according to their density. Separation is accomplished by a jet of air. The shredded material is fed into a moving air current which results in the fluidization of the material. Light density material such as paper, fine particles, film, and foil are carried up and out of the classifier, whereas heavy material such as metals and glass drop down. There are various types of air classifiers depending on the type of chute and the direction of air flow. They are illustrated in Figures 3-19 to 3-25. The

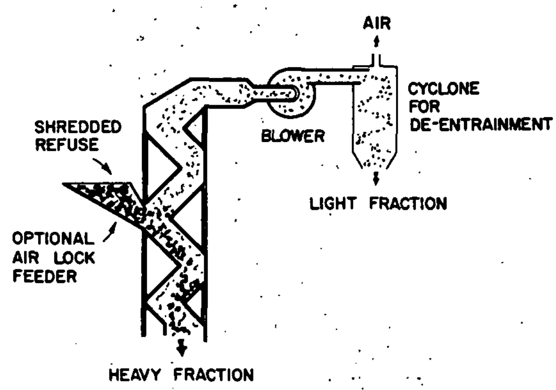


FIGURE 3-19
ZIG-ZAG AIR CLASSIFIER

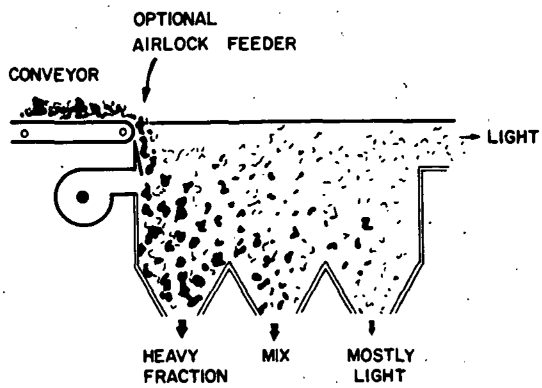


FIGURE 3-20
HORIZONTAL AIR CLASSIFIER

*From catalogs and information furnished by Eriez Magnetics Company, Erie, Pennsylvania 16512.

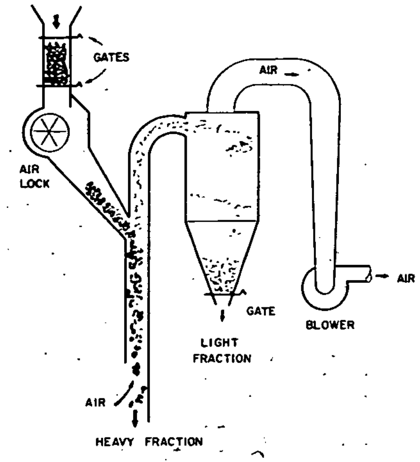


FIGURE 3-21
VERTICAL AIR CLASSIFIER

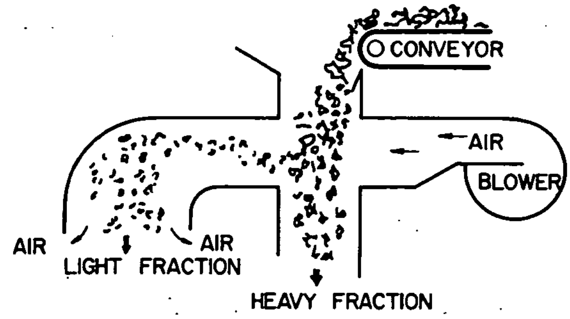


FIGURE 3-24
CROSS FLOW AIR CLASSIFIER

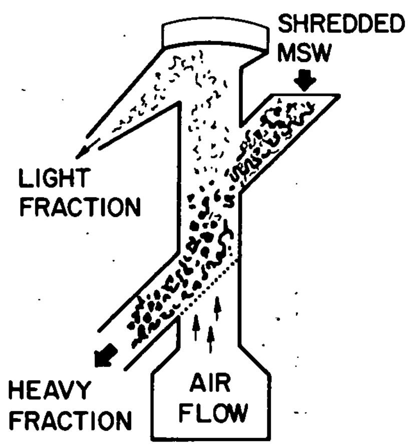


FIGURE 3-22
SORTEX AIR CLASSIFIER

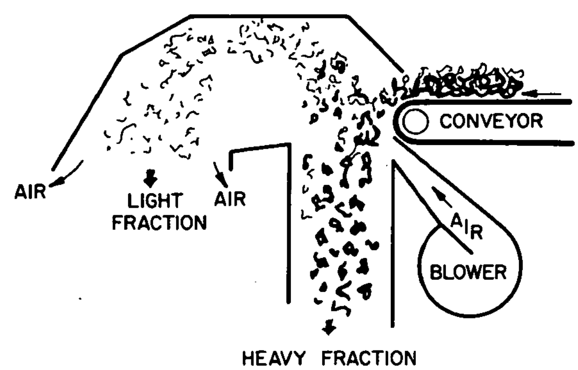
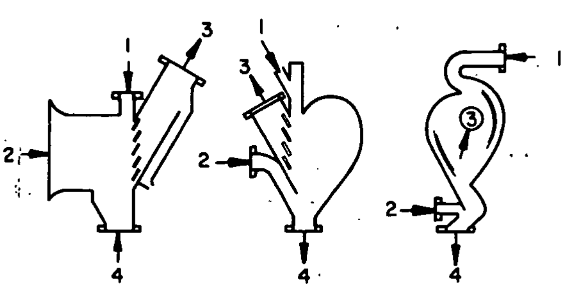


FIGURE 3-25
IMPULSE TYPE AIR CLASSIFIER



KEY

1 SHREADED REFUSE IN
2 AIR IN
3 LIGHT FRACTION OUT
4 HEAVY FRACTION OUT

FIGURE 3-23
VANE/ROTATIONAL AIR CLASSIFIER

Zig-Zag air classifier made by Scientific Air Separators, Inc., Denver, Colorado, was used in a laboratory study made by the Stanford Research Institute, Irvine, California. At present, no large-scale performance data on air classifiers are available (ref. 3-11).

The horizontal air classifier has been tried by the U. S. Bureau of Mines in Salt Lake City on shredded automobiles. The vertical type of air classifier manufactured by Rader Pneumatics, Inc., Memphis, Tennessee, is being commercially used to separate nails from wood chips at a pulp mill (109 metric ton or 120 ton capacity). Other examples of vertical air classifiers are those manufactured by Sortex Company, Lowell, Michigan, a unit of which is being used in the Black-Clawson resource recovery demonstration plant at Franklin, Ohio (ref. 3-11).

The cyclone type of air classifier has been used commercially by Reynolds Aluminum Company at its pyrolysis aluminum recovery operation at Bellwood, Virginia, smelting plant to recover aluminum from paper-mounted foil. The cross flow type of air classifier is commercially used in junk automobile shredder facilities for cleaning shredded metals. The impulse type of air classifier manufactured by Williams Shredder Company is commercially used to recover fabrics and other light material from shredded automobile bodies.

The laboratory size test on solid waste made at the St. Louis processing plant for the Horner-Shifren project gave 2 to 39 percent input as heavy fractions using Williams air classifiers. Application of air classifiers for separating shredded cans from shredded municipal solid waste has been suggested by Swindell, Dressler Company. The rotational type of air classifier, manufactured by Buell Engineering Company, Lebanon, Pennsylvania, has been commercially used in potash, limestone, phosphate, and alumina hydrate separation.

The Osborne dry separator is a mechanical device for separating presized material of different specific gravities by the pulsation of a stream of air through a bed of the material. It was used in San Fernando and is reported successful in removing glass and other similar material from compost. Some of the operation details are given in Table 3-5.

TABLE 3-5
CHARACTERISTICS OF THE OSBORNE DRY SEPARATOR

Size:
- Length (7 ft. 7 in.) 2.6 m
- Width (5 ft. 0 in.) 1.5 m
- Height (7 ft. 3 in.) 2.5 m

Feed rate based on composed municipal solid waste: 1.4 metric ton/hr (1½ tons per hr.)

Particle size:
- Maximum:
  - Inorganic fraction (3/10 in.) 4.8 mm
  - Organic fraction (1 in.) 2.54 cm
- Minimum:
  - Inorganic (1/64 in.) 0.4 mm Battelle estimates
  - Organic (3/16 in.) 4.8 mm Battelle estimates

Separation:
- 90 to 95 percent of the glass, sand, metals, and other heavy fractions are removed from the finished composts

Cost:
- $25,000.00 approximately.

3.2.3.5 OPTICAL SORTING

Optical sorting machines make use of light-reflection properties of material and separate particles on the basis of color. This has been quite successful in agricultural and food processing industries. Figure 3-26 illustrates diagramatically the operating principle of a unit manufactured by Sortex Company of North America. To ensure proper operation, all light sources and optical components are kept clear of dust particles by a low-pressure air curtain. Sortex produces three models ranging up to 45,350 kilogram/hour (50 tons/hour) capacity. Particle size may vary from 6.2 milometers (0.25 inches) to 152.4 milometers (6 inches) for optimum efficiency. The 45350 kilogram/hour machine costs about $61,000 (ref. 3-8).

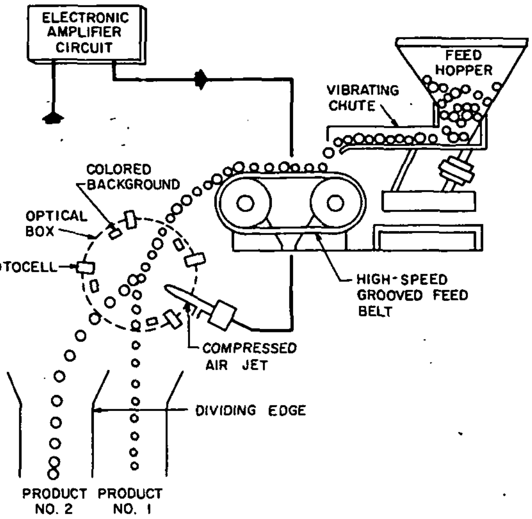


FIGURE 3-26
SCHEMATIC DIAGRAM OF AN OPTICAL SEPARATOR

Another form of optical sorting was developed by Battelle Memorial Institute for the removal of dark impurities from rock salt and combines a thermoadhesive process with optical phenomena (ref. 3-12, 3-13). So far, this has been applied for solid waste processing only on testing basis (ref. 3-14) and has high potential for the recovery of rubber and plastics.

3.2.3.6 INERTIAL SEPARATION

The material is separated in this process on the basis of air resistance and density of the particles. Figure 3-27 from ref. 3-8 illustrates different

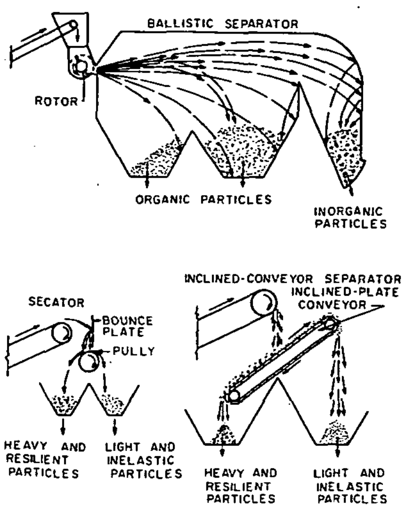


FIGURE 3-27
TYPES OF INERTIAL SEPARATORS

types of inertial separation principles. Inertial separation has not been successfully applied to the separation of solid waste.

3.2.3.7 EDDY-CURRENT SEPARATION

The separation of the nonmagnetic conductive materials (copper, aluminum, and zinc) from the solid waste has been tried by using eddy-current phenomena. It has still to be developed to become technically promising (ref. 3-15). This device consists of a drum with a series of magnets around its interior surface. By rotating the drum, a changing flux is produced in the magnetic field induced outside the drum. When nonmagnetic conductive material is placed in the changing field, eddy-currents develop in the material and a repulsive force is generated. If this force is sufficiently strong, it will deflect the material and effect separation. However, the repulsive forces developed, to a great extent, depending on the size, shape, and surface irregularities of the material. The principle is illustrated in Figure 3-28.

3.2.3.8 HIGH-INTENSITY, ELECTROSTATIC SEPARATION

High-intensity, electrostatic separators are used to separate glass and aluminum in the residue left after processing municipal solid waste. Feed material is exposed to an electric charge. The materials accept the charge, but the conductors retain the charge only for a short while. The nonconductors, which

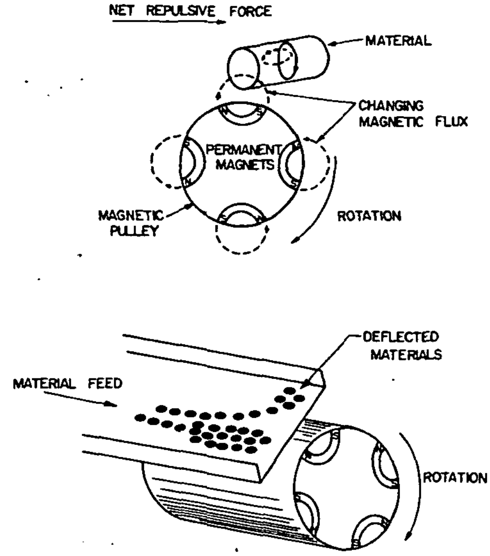
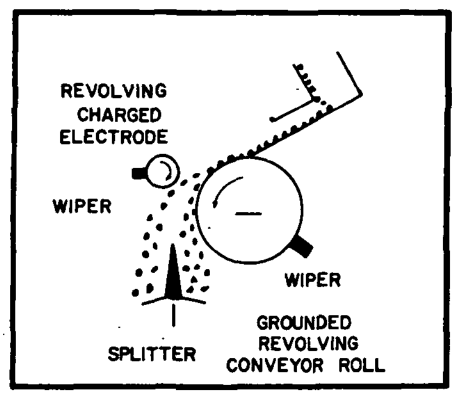


FIGURE 3-28
SCHEMATIC OF PULLEY-TYPE
EDDY CURRENT SEPARATOR

retain charge, adhere to an oppositely charged drum, while the conductors drop off immediately. As separation is size sensitive, the process will have to be repeated for different size fractions at several stages. Figure 3-29 (from ref.



CHARGED ELECTRODE SELECTIVELY PULLS
MATERIAL BEYOND FLOW SPLITTER

FIGURE 3-29
PRINCIPLE OF HIGH VOLTAGE
ELECTROSTATIC SEPARATOR

3-10) illustrates the principle of electrostatic separators. The equipment manufactured by the Dings Company and the Carpco Company have been used in the food and mineral processing industries, but testing with MMR has been restricted to the laboratory. These tests, however, have been quite encouraging (ref. 3-10). The engineering feasibility study of Materials Recovery System by the National Center for Resource Recovery, Inc., has reported that the cost of the electrostatic separator to handle about 1814 kilogram/hour (2 ton/hour) is $25,000 at 1972 prices (ref. 3-10).

3.2.3.9 OTHER TYPES OF SEPARATORS

Some other types of separation methods used in the field of separation technology are jigs, stoners, heavy-media separation, etc. Most of these methods make use of the varying densities for their separation. They are sometimes classified as wet methods.

Flotation methods can be adopted for separating light organic material, from heavier inorganic material. Such a type of separation may be economical for biodegradation processes, as no drying of the feed material is needed for that process.

Flotation methods are also used for the separation of light metals such as aluminum from denser material such as glass. As high-density liquids are used in such processes, they are classified as heavy-media separators. By changing the density of the liquid, material of one density in the mix can be made to float and another denser material in the mix can be made to sink. In some processes, this procedure is used to separate aluminum from glass in the residue of MMR. Froth Flotation, a proprietory method using the same principles as discussed above, is used for glass recovery (ref. 3-16).

Jigging, Wilfley tables, and sweating are some other methods used in the mining industry to extract minerals from their ores. At present, these methods are not suitable for application to extraction of metals from solid wastes.

Another way of separating materials on the basis of variations in specific gravity is stoners. A stoner is basically a dry vibrating table that operates by passing a current of air upward through an inclined screen. Feed enters the inclined screen from the top end. By proper installation of baffles and by control of position of inlet of feed, material of different categories can be separated. Sutton, Steele, and Steele stoners used in the Houston plant (Lone Star Organics, Inc.) cost about $10,000 each and the cost of screening equipment used along with it was another $8,000. Power requirement is hardly 0.8225 Watts/kilograms (1 horsepower/ton) per hour. Figure 3-30 shows the relationship between cost and capacity of stoners, according to Sutton, Steele, and Steele Company (ref. 3-8).

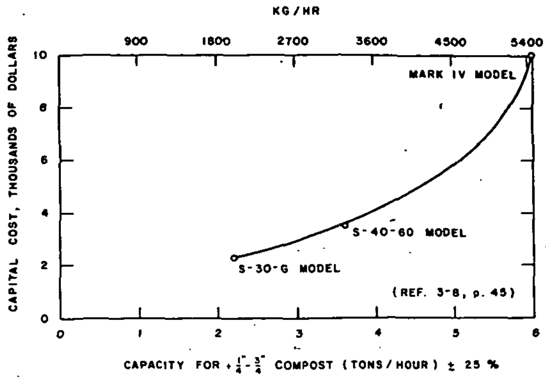


FIGURE 3-30
CAPITAL COST OF SUTTON, STEELE, AND STEELE STONERS

3.2.4 SEPARATION AND SIZE REDUCTION AS A TERMINAL PROCESS

3.2.4.1 GENERAL

Some combination of the various separation and size reduction techniques, described previously, almost always is required in preparing MMR for further processing by incineration, pyrolysis, or biodegradation methods in the conversion and recovery of energy products and resources. Because of this initial position in the overall conversion system, such combinations of separation and size reduction steps often are referred to as "front-end" systems or processes.

There can be a number of reasons (these are discussed in Chapter 5) why a municipality may not wish to, or is not able to, consider further conversion of MMR by incineration, pyrolysis, or other means. In such instances, the utilization of a front-end process as a terminal process in its own right may be one of the systems alternatives to be considered in solving a solid waste problem.

Several systems alternatives involving separation and/or size reduction as terminal processes are available for consideration by municipal authorities. Proceeding from the simple to the complex, these may be categorized as follows:

1. Size reduction alone.

The process of size reduction (by any of several methods) may reduce the physical volume of MMR by up to 50 percent of its original bulk. This is an important advantage if landfill is the ultimate destination of the MMR and if landfill sites are scarce, expensive, or a considerable distance from collection points. This is an expensive way of achieving a single advantage in many situations; however, it is comparatively easy to make a simple economic comparison to see if the decreased landfill disposal costs of the reduced volume offsets the size reduction processing costs.

2. Size reduction with separation of materials resources.

If after fragmentation of the MMR, separation steps are added for the recovery of significant amounts of constituent resources (metals, glass, paper, etc.), then further advantages are gained. Credits are obtained for the recycled materials. The reduction in physical volume of the residue destined for landfill is greater than for size reduction alone. The Black-Clawson process will be discussed in more detail in a later section as an example of a resource recovery plant.

3. Size reduction and separation with recovery of materials resources and an energy product.

MMR may be fragmented and valuable materials resources separated and recovered. The residue, which contains a high percentage of organic material, may be dried and further pulverized if needed. The resultant product has a heating value on the order of 1.74×10^7 joules/kilogram (7,500 Btu/pound) and represents about 60 percent, by mass, of the original MMR. This dried, pulverized product can be burned as a fuel in suitably designed facilities, used in an incinerator with or without supplemental fuel, or comprise the feed stock for a pyrolysis process.

The advantages of this third category of alternative are threefold:

1. An even greater reduction in the volume of residue going to landfill as compared with the previous two categories,
2. Credits for recycled materials, and,
3. Credits from either local use or sale of the energy product.

The Eco-Fuel™ production process is one example of this category of systems alternative. Another is the Garrett process. In actual fact, the complete Garrett process is a pyrolysis process; however, its front-end portion is a well-designed process; which produces a dried, pulverized fuel somewhat similar to Eco-Fuel™. Both Eco-Fuel™ and the Garrett front-end system are described from the terminal process viewpoint in the sections immediately following.

3.2.4.2 ECO-FUEL™ AS A TERMINAL SYSTEM (ref. 3-17)

Combustion Equipment Association, Inc. of New York, has developed a front-end system that is principally oriented toward energy recovery. The output product from this system is called Eco-Fuel™ which is a marketable solid fuel. The first generation front-end system produced a fuel called Eco-Fuel™I. A flow diagram of the Eco-Fuel™I system is shown in Figure 3-31.

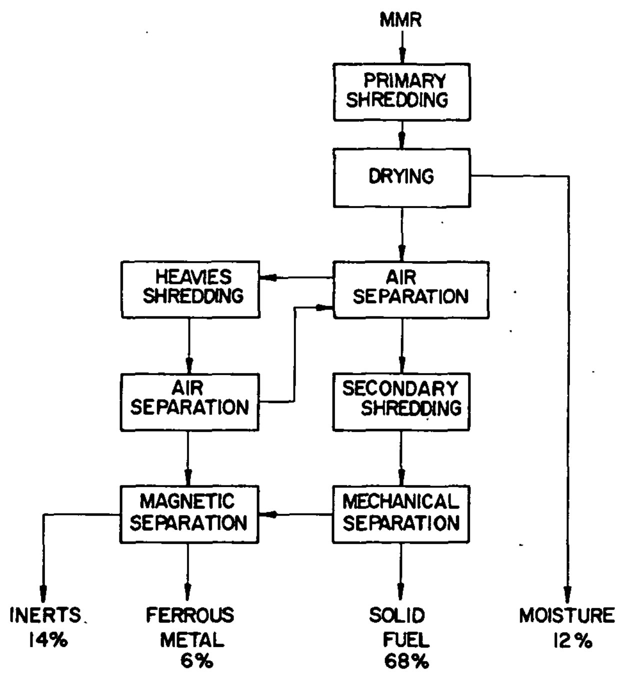


FIGURE 3-31
ECO-FUEL™ I
PROCESS FLOW DIAGRAM

The Eco-Fuel™ I process consisted of two stages of shredding, the first stage being a flail mill discussed previously, and two stages of classification and drying to produce a controlled moisture, low-ash shredded fuel. In this process solid waste is picked up from the storage area by a front-end loader and delivered to a conveyor system that feeds the primary shredder. After shredding, the material is dried and classified to separate the heavier non-combustible fraction from the lighter combustible fraction. The lighter fraction undergoes further size reduction and classification (a mechanical separator) to remove more of the non-combustibles. The resulting product is Eco-Fuel™ I.

The Eco-Fuel™ II system has been modified to obtain more efficient size reduction and drying in an attempt to obtain a pulverized fuel that contains less moisture and thereby yields a higher heating value. In this process, solid waste is shredded by a flail mill and conveyed to a magnetic separator for ferrous metal removal. The separated fraction is classified and the fine particles (mostly inerts) are removed, the oversized particles are reshredded, and the balance is sent to the secondary size reduction operation. In the secondary size reduction operation, a chemical is added to act as a catalyst and aid in the size reduction operation. Finally, the product is screened and classified to yield Eco-Fuel™ II. The final size of the Eco-Fuel™ II can vary to as small as 100 mesh, depending on the type of burner used in the incineration process. Further developmental tests will be conducted to determine optimum particle size for incineration, according to Ken Rogers of CEA, Inc., in a telephone conversation on 6 August 1974. Since the fuel is in solid form, it is easily stored and transported. More information on the incineration characteristics of Eco-Fuel™ II will be given later in the Incineration section. (See figure 3-32)

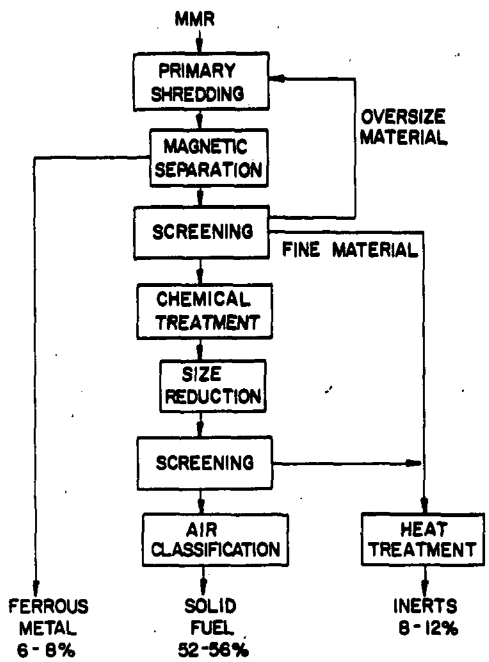


FIGURE 3-32
ECO-FUEL™ II PROCESS FLOW DIAGRAM

3.2.4.3 GARRET FRONT-END PROCESS

The Garrett front-end process is designed to recover from the mixed municipal refuse nearly all the glass and ferrous metals, and to convert the organic into a dry solid fuel which may be used for pyrolysis or incineration. This process involves coarse shredding of the raw, wet refuse; air-classification to remove most of the inorganics; drying of the organics to a moisture content of 3 percent by weight; and secondary crushing to a nominal -28 mesh. Ferrous metals are magnetically reclaimed from the classifier rejects and a sand-sized, mixed-color glass cullet of +99.7 percent purity is recovered from the remaining inorganics by selective crushing and screening followed by a proprietary Froth Flotation process. The preparation of the material for the process involves the following sequential major operations.

Primary Shredding: The mixed municipal refuse is shredded to about 2.5 centimeters (1 inch) size. In most cases, the reduction to 2.5 centimeters (1 inch) size involves two or three stages of shredding.

Primary Air Classification: The shredded material is next subjected to air classification by a simple zig-zag unit. Air classifiers of about 0.61 meters by 0.61 meters (2 feet by 2 feet) fitted directly to the discharge chute of the end shredder are quite effective.

Drying: The average moisture content of MMR is about 25 percent. The shredding and air classification reduces the moisture content to some extent. If the moisture content has not been reduced to below 5 percent as needed for the pyrolysis process, then the air-classified organic matter must be dried.

Screening: Two-deck screening using 0.61 centimeters (¼ inch) and #14 mesh, can eliminate nearly 85 percent of the inert material.

The fines are subjected to a proprietary froth flotation for recovery of glass. A secondary screening follows to ensure that the fines are 90 to 95 percent free of inorganic material.

Milling: The undersize of 0.63 centimeter (¼ inch) from screening contains almost 95 percent glass, which is ground in two stages. After first grinding all +8 mesh material which contains mostly plastics and rubber is recovered. In the second stage of finer grinding, the material which is finer than 32 mesh and coarser than 200 mesh is subjected to Froth Flotation.

Froth Flotation: This is a proprietary separation process which claims selective flotation with selective reagents. The material is magnetically cleaned to remove any remaining ferrous metal. The remaining product is pure, sand-sized, mixed-color glass that can be used directly by glass manufacturers.

Secondary Shredding: The organic material to be fed into the pyrolysis unit needs fine shredding. It should have gradation consistancy of at least about 70 percent smaller than 24 size mesh. A typical size distribution of prepared material for the Garrett process is shown in Table 3-6. These data are from a pilot study conducted by the County of San Diego, California.

TABLE 3-6
SIZE DISTRIBUTION OF GARRETT
SECONDARY SHREDDED SOLID WASTE
Organic Portion Only

Size			Cummulative
Tyler Mesh	Microns	Wt. % Retained	Wt. % Retained
¼ inch	6350	6.0	6.0
16	991	21.0	27.0
20	833	3.9	30.9
32	495	19.1	50.0
48	295	11.7	61.7
80	175	9.1	70.8
100	147	4.8	75.6
150	104	4.6	80.2
200	74	4.9	85.1
Minus 200	Minus 74	14.9	100.0

Note: Solid waste ground to this size is of a matted, fibrous nature. Screen size is not an accurate measure of particle length or width particularly above 20 mesh where considerable "balling" is apparent. (ref. 3-18)

3.2.4.4 BLACK CLAWSON PROCESS

The Black Clawson Company developed for the city of Franklin, Ohio, a solid waste disposal and reclamation system based primarily on a system of fiber recovery through hydropulping (ref. 3-19).

The system also centrifugally removes metal and glass, and dewaters and burns the remaining material in a fluid bed reactor.

In the preliminary design study it was discovered that sewage sludge could be mixed with the separation residue and disposed of by incineration. The sewage sludge can be in either a raw, activated, or digested state and no longer needs coagulents for dewatering. The remaining fraction of the MMR, after metal and glass removal and fiber recovery, provides sufficient heating value to burn the sewage sludge in the fluid bed reactor.

Figure 3-33 shows the basic flow sheet for the combined solid waste and sewage treatment plants. The solid waste plant uses the secondary clarifier effluent for process and scrubber water. The solid waste processing produces 189 liter/minute (50 gallon/minute) of waste water which is treated by the water treatment plant. The remaining fraction of the MMR is mixed with sewage sludge, primary and secondary, and incinerated in the fluid bed reactor. The scrubber output water, containing suspended ash, is mixed with the industrial waste water. The water-suspended ash works as a settling agent in the industrial clarifier, and the plants can use common utilities and service facilities. After processing, with 95 percent effective volume reduction by recovery and incineration, the 5 percent that remains is organic, non-toxic, and inert. This can then be safely landfilled.

The fluid bed reactor is approximately 7.32 meters (24 feet) in diameter and 9.14 meters (30 feet) high. The bottom plate is perforated and is covered with approximately 1.21 meters (4 feet of sand. The sand is suspended by air blown up through the perforated. plate. For cold start of the furnace, the sand is preheated to 649°C (1,200° F) by oil burners. This requires 9.45 x 10^3 liters of fuel. The finely chopped solid waste is introduced into the hot fluidized bed and contact heating by the sand causes complete combustion. The combustion products have a reactor exit temperature of 816°C (1,500°F) and are water cooled and washed to remove the fly ash.

The plant that processes the reactor feed is a preprocessing and recovery system. MMR is fed into a hydropulper where the pulpable and friable materials are size reduced so as to pass through the 1.91 centimeter (0.75 inch) diameter openings in the hydropulper extraction plate. This is slurried to 3 percent to 3.5 percent and pumped into typical paper milling operations. The hydropulper continuously ejects nonpulpable materials which are predominately ferrous metals.

The slurry is next treated in a liquid cyclone to remove larger particles. This reject is 80 percent glass and 20 percent aluminum, other metals, and dirt. Next the non-fiberous organics such as plastic and leather are removed by a screen of 3.2 millimeter (1/8 inch) mesh. The material that passes through this screen is now diluted to a 0.5 percent consistency and passed through an average 1.59 millimeter (1/16 inch) mesh paper mill screen which removes the remaining non-papermaking fibers. Following this, fine sand and fine fibers are removed by centrifugal cleaners. The remaining acceptable

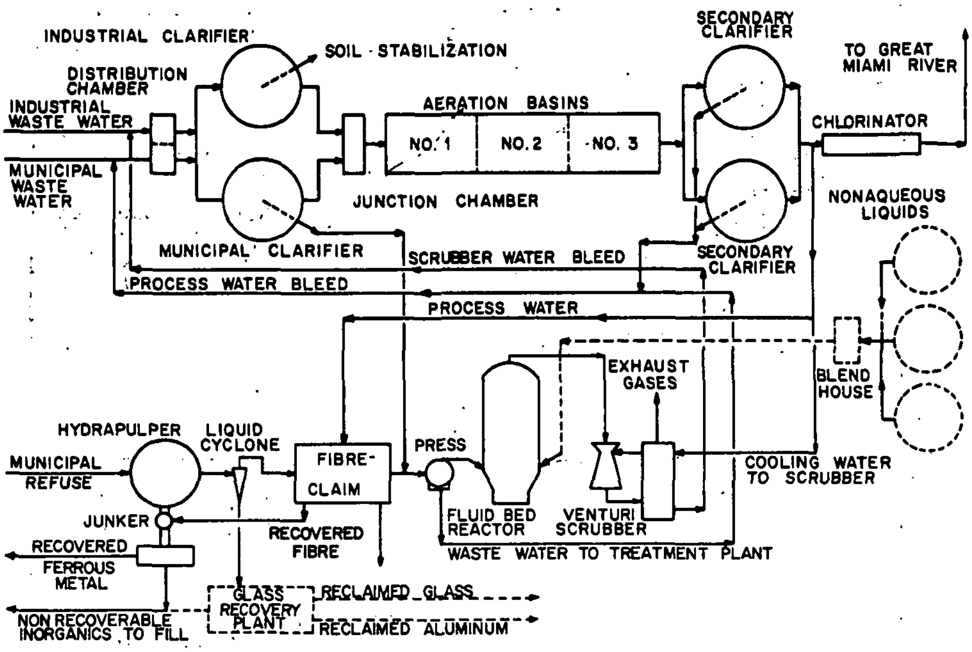


FIGURE 3-33
BASIC FLOW DIAGRAM FOR BLACK CLAWSON PROCESS

material is dewatered, given a controled mild caustic treatment, dewatered again, and finally baled.

All the rejected non-recyclable material, chiefly organic, is mixed with sewage sludge. The mixture is dewatered to 40 percent solids and used as furnace feed.

The plant is designed for a nominal capacity of 136 metric ton (150 ton) 24 hour day. It now runs for an average of 8 hours/day. The calculated amount of materials recycled in an 8 hour day are given in Table 3-7.

TABLE 3-7
CALCULATED AMOUNT OF MATERIALS RECYCLED PER 8-HOUR DAY

	Metric Ton/8 hour day	Tons/8 hr day
Paper Fiber	7.26 to 9.07	8 to 10
Ferrous Metal	4 to 5	4 to 5
Glass (crushed)	2 to 3	2 to 3

The economics of the Black Clawson process are based on the market conditions in Franklin, Ohio. The Black Clawson process came on line with 136 metric ton/day (150 ton/day) plant in 1972 and added a resource recovery operation for aluminum and glass in early 1974. Because of this, the report data from the two latest reports, EPA's Second Report to Congress (1974), (ref. 3-20) and Schulz, et.al. (ref. 3-21) 1973 are perhaps most reliable. The process costs from these sources are given in Table 3-8 for various plant sizes. The resource recovery data are also listed in Table 3-8. The analysis of EPA data for the 454 metric ton/day operation with resource recovery and source reduction gives a net of $9.75 per metric ton ($8.83 per ton) for processing Franklin, Ohio's waste. An analysis of Schulz's data for the same size plant, gives a slightly different disposal cost.

Scaling the plant size up to 1814 metric ton/day (2,000 ton/day) using Schulz's data gives a similar cost per ton for disposal of Franklin's solid waste. In this case scale size produces a metric ton cost of $8.50 ($7.70 per ton). Thus increasing plant size by a factor of 4, produces no significant savings either on process costs or on resource recovery.

TABLE 3-8 (A)
ECONOMIC DATA-BLACK CLAWSON PROCESS
PROCESS COST SHEET

Process Name: Hydraposal/Fiber Claim System of Black Clawson

Data Source: EPA's Second Report to Congress-1974 (ref. 3-20)

Capacity in Tons/Day: 454 Metric Tons (500 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt	(a)	(a) No details given on cost break down
Processing Eqmt		
Postprocessing Eqmt		
Utilities	(b)	(b) Actual Plant in operation is 136 metric tons/day (150 ton/day)
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	8,300,000	
OPERATING COSTS ($ PER YR)		
Maint. Material	(c)	(c) Assume 300 day/ year operation
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead		
Utilities	1,500,000(d)	(d) Operation and maintenance
Taxes		
Insurance		
Interest		
Disposal of Residue		
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	1,500,000	
CREDITS ASSUMED ($ PER YR)	975,000	

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid	None	(a) Based on 165,000 metric tons/yr (150,000 tons/yr)
Gas		
Solid		
Power:	None	
Steam		(b) Fe @ $14.90/mt ton ($13.50/ton)
Electricity		
Hot Water	(a)	
Magnetic Metals	127,500(b)	(c) AL @ $220/mt ton ($200/ton)
Nonmagnetic Metals	120,000(c)	
Glass	75,000(d)	
Ash		(d) $13.20/mt ton ($12/ton)
Paper	562,500(e)	
Other: sewage sludge disposal	90,000	(e) $27.60/mt ton ($25/ton)
TOTAL ($ PER YR.)	975,000	

TABLE 3-8(B)
ECONOMIC DATA-BLACK CLAWSON PROCESS

Process Name: Hydraposal/Fibre Claim System of Black-Clawson

Data Source: Schulz Report (ref. 3-21)

Capacity in Tons/Day: 1814 Metric tons (2000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land	(a)	(a) No detail given
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities	(b)	(b) Actual plant operating at 150 ton/day
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	36,000,000	
OPERATING COSTS ($ PER YR)		
Maint. Material	(c)	(c) Assume 300 da/yr operation
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead	6,180,000	
Utilities		
Taxes		
Insurance		
Interest		
Disposal of Residue	300,000 (d)	(d) $.55/metric ton of residue ($0.50/ton) charge
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	6,480,000	
CREDITS ASSUMED ($ PER YR)	4,998,000	

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid	None	(a) 1.19 x 10^9 Joules/metric ton at $2.78/$10^9$ joules (300 KWH/ton at $.01/KWH)
Gas		
Solid		
Power:		
Steam		
Electricity	1,800,000 (a)	
Hot Water		
Magnetic Metals	450,000 (b)	(b) $11.00/metric ton ($10.00/ton)
Nonmagnetic Metals	672,000 (c)	(c) $221/metric ton (200/ton)
Glass	240,000 (d)	(d) $11.00/metric ton ($10.00/ton)
Ash		
Paper	1,836,000	
Other:		
TOTAL ($ PER YR.)	4,998,000	

Each source and plant size, regardless of the different assumptions, yields about the same cost of disposal, namely $8.00-$10.00 per metric ton of refuse. It should be noted that these figures can still vary with the resource recovery credits obtained. For both sources, the ratio of operating costs to revenue is about the same, i.e., ranging from 1.9 to about 2.6. The feasibility of application of the Black Clawson process must depend heavily on the actual credit obtained in a specific area for the recovered materials. Particular attention must be paid to the market for paper and paper pulp.

Schulz, in his report, gives a credit for steam. Without this rather large credit, his operating cost/revenue ratio goes from 1.92 to 3.01. The justification of this credit is questionable since the only reasonable use for the steam in the Franklin, Ohio, case appears to be in the sewage disposal plant. In other locations the steam market may be different. Also, the EPA's projection of the costs should be better since its figures are based on a longer operating time under actual 136 metric ton (150 ton) day operating conditions. It should be noted that the present recovery system still produces about 10 tons of solid residuals per 100 tons of MMR delivered to the plant. These residuals must be landfilled at this time in Franklin. The use of the residue for aggregate should be considered as a possible additional credit to reduce the cost of landfill.

3.3 INCINERATION PROCESSES

3.3.1 INTRODUCTION

The solid waste problem and the energy shortage have focused the attention of engineers on possible methods of energy recovery from solid waste. Since certain areas of Europe have been producing steam from the firing of refuse for many years, it is only natural that some of our current technology is patterned after European practice.

The primary reason for incineration of refuse is volume reduction. A typical incineration process might reduce the volume of refuse by 92 percent, while reducing the weight by 80 percent. The residue from thermal reduction processes is inert, and may be landfilled or used, in some cases, as a building material. Incinerators built prior to 1968 were not well designed by today's technological standards and were generally viewed unfavorably by the public. Modern energy recovery incinerator plants are more acceptable today and are expected to meet most local, state, and federal air pollution standards (ref. 3-22).

In this section, a number of incineration processes will be discussed. The particular systems are:

1. Typical water-wall incinerators for steam generation.
2. C. P. U. 400 system for electrical power generation.
3. Supplemental fuel systems for steam generation.
4. Direct incineration of prepared refuse in boilers for steam generation.

A cursory technical description of the above incineration processes will be followed by a detailed description of one typical process selected from each of the above four incineration areas. The detailed description will also include economic data.

3.3.1.1 COMPOSITION LIMITS FOR SELF-BURNING REFUSE

Many persons believe that municipal refuse can be burned only by the use of additional coal, oil, or gas. This has rarely been the case. Many incinerators are equipped with auxiliary oil or gas burners to keep the system warm when no refuse is being fired, for initial ignition of wet refuse, or to dispose of waste oils collected separately from the refuse. Von Roll of Zurich, Switzerland, as pointed out by Leatham (ref. 3-23) present the following three-coordinate chart, Figure 3-34, to illustrate the wide range of refuse which can be burned without auxiliary fuel.

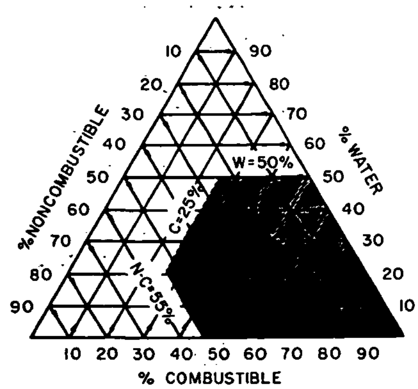


FIGURE 3-34
COMPOSITION LIMITS FOR SELF BURNING OF REFUSE

The amount of heat that MMR will produce, when burned, depends upon its ash content, its moisture content, and the nature of the combustible components. Increased use of wastes from packaging and the decreased amounts of furnace or stove ashes has caused a continual increase in the heating value of refuse worldwide. It takes about three pounds of refuse to equal a pound of presently available bituminous coal in the production of steam. The non-uniformity of refuse plus relatively high ash and moisture content results in a furnace and boiler efficiency of about 65 percent in the best of modern incinerators; whereas gas, coal, and oil fired units are capable of performing at efficiencies greater than 80 percent.

3.3.1.2 STOKERS

In Europe thick fuel bed burning is universally practiced. The stoker hopper is fed by a traveling crane with a grapple. During the last 12 years, as reviewed by Astrom, et.at., (ref. 3-24), and Roberts, et.al., (ref. 3-25) a few manufacturers have developed grate designs that have managed to obtain a strong foothold in the European market. They are all based on a moving grate, but the movement varies in type. Normally complete incineration is only obtainable with a moving grate, since a regular movement of the fuel bed is not possible on a stationary grate due to the varying size of waste pieces and varying density of the refuse.

The Von Roll system uses a sloping grate stoker. This stoker is composed of three separated grates independently driven. The speed of each grate, as well as the combustion air distribution, can be controlled to insure satisfactory combustion. The three grates are sloped at approximately 15 degrees downward. The middle section, on which most of the burning takes place, is equipped with mobile knives which stir the burning bed to achieve complete combustion. The first section is the drying grate. The second and third are, respectively, the burning grate and finishing grate. This type of stoker is a forward acting grate.

The Martin system has a reverse reciprocating stoker which functions similar to a forward acting grate. This grate design is used in Europe and North America.

3.3.1.3 FURNACE AND HEAT EXCHANGE EQUIPMENT

The furnace can be water-walled. This is an effective means of heat recovery which utilizes furnace walls made of closely spaced steel tubes welded together, with water or steam circulated through the tubes to extract heat from the combustion zone. The decision as to heat recovery economics is governed primarily by the nature of the local fuel market, including availability, price, and demand patterns.

The water-walled furnace with integral boiler, superheater, and economizer (in a later pass) or the refractory lined furnace with a waste-heat type of boiler mounted in the outlet flue can be used for energy recovery. In any event, the design of the grate, furnace, and heat exchange surfaces must consider the special characteristics of refuse as a fuel. Heat release per square foot of grate will be considerably less than for coal even though the weight and volume of fuel may be much greater. Furnace temperatures must be maintained within the range of 760°C (1400°F) to 982°C (1800°F) to insure destruction of all odors without fusing fly ash to walls or tubes (ref. 3-24, 3-25).

3.3.1.4 PARTICULATE EMISSION

The flue gases contain solid and gaseous pollutants. The concentrations vary from one plant to another as presented by Jeffers and Nuss (ref. 3-1). The dust content, entering the precipitator varies from 3.43×10^{-3} to 1.72×10^{-2} kilogram/meter^3 (1.5 to 7.5 grains/SCF). As a mean value, normally, 8×10^{-3} kilograms/meter^3 (3.5 grains/scf) is used.

The sulfur oxides content is usually small compared to gases from oil or coal burning because of the low sulphur content in refuse. A major part of sulfur oxides may be from auxiliary fired fuel. Massey, et.al., (ref. 3-26) indicated that municipal refuse sulfur content has been measured as 0.12 percent of the ultimate analysis, as compared with up to 3 percent sulfur in coals used for power generation.

Formation of hydrochloric acid can become a technical environmental problem. With a PVC-content of 2 percent, the flue gases contain 690 PPM HCl and a 12 percent CO_2 level. No regulations currently exist concerning allowable HCl emissions. HCl can be removed by scrubbing the gases in water. However, it is not easily separated from water and can cause a water pollution problem.

Particulate Emission Control Devices

There are four basic types of particulate collection devices, discussed by Jackson, (ref. 3-22) and White (ref. 3-27).

-Mechanical Collectors	-Wet Scrubbers
-Electrostatic Precipitators	-Fabric Filters

Mechanical Collectors

These devices use centrifugal forces to separate particulates from gas streams. The gas is introduced tangentially which causes the particulates to be separated from the gas stream. Mechanical collectors are selective with respect to particle size and density. These collectors can be expected to exhibit 75 to 80 percent collection efficiencies on suspension-fired systems.

Wet Scrubbers

These devices wet the particulates entrained in the flue gas. The size and weight of the particle is effectively increased by this wetting, so they can then be mechanically separated. Scrubber performance depends on the turbulence of the gas, liquid droplet-size, and the amount of scrubber liquid used. Although capable of much higher collection efficiency, scrubbers require higher power inputs than mechanical collectors. The wet scrubber requires about the same physical space as a mechanical collector, but the associated water-and ash-handling equipment can require additional space of 2 or 3 times the scrubber space requirements.

Fabric Filters

The stack gas is passed through a filter cake of collected ash deposited on the fabric envelope. The collection efficiency of fabric filters is 99 percent or greater. Simplicity and good performance make these systems attractive, while space requirements and pressure drop are serious disadvantages. The operational costs of this collection system are high.

Electrostatic Precipitators

These collectors use high intensity electrical fields to separate particulates electrostatically from flue gases. Although relatively insensitive to particle size variation, precipitators depend on particle resistivities that are consistent with effective operation. White (ref. 3-27) has indicated that fly ash resistivities below 10^{12} ohm-cm are considered good for electrostatic precipitation.

Single-stage electrostatic precipitators will remove up to 99.5 percent of entrained fly ash. Space requirements are similar to those for fabric filter collectors. The operating cost for electrostatic precipitators is low. The performance for precipitators is a function of the particle velocity within the collection unit. This velocity determines the overall size and cost of the precipitator, as stated by ref. 3-25 .

3.3.1.5 ENERGY OUTPUT AND USE

Some of the new incinerator plants are designed with energy output. This energy is in the form of steam or electricity. The steam output holds primary significance in systems such as the supplemental fuel boiler and the direct fired refuse boiler. The steam can be sold to nearby users for such purposes as heating, cooling, equipment testing, and electric power generation. Of all the resources that can be obtained from refuse, including recycled materials, steam is probably the most valuable, if a market is available.

Part of the steam generated can be used for plant power. Steam is normally used in the plant for the undergrate heater, sootblowers, building heat, and the turbine drive for the shredder. The remaining steam is available for export and sale.

Another approach to utilizing the energy of refuse is to use products of combustion to power a normally gas-driven turbine generator. The advantage of a turbine generator is that the turbines can be put on and off line rather rapidly. The CPU-400 is a system of this type which will be discussed later.

3.3.2 DESCRIPTION OF INCINERATOR PROCESSES

3.3.2.1 TYPICAL INCINERATION PLANTS WITH ENERGY RECOVERY

Most modern heat recovery incinerators use a water-walled furnace, the combustion gases exchange heat in the boiler section, superheaters and economizer, causing a gas temperature reduction from 1371°C (2500°F) to 232°C (450°F) (ref. 3-26). The gases then enter the electrostatic precipitator for removal of the particulate matter within prescribed limits. The boiler is not only a steam generator, but also is an efficient means to cool the furnace gases. This acts to prolong the life of the furnace. Only energy recovery systems will be discussed, and Table 3-9 contains technical data on five selected energy recovery plants.

3.3.2.1.1 Description of Water-Wall Incineration Plants

Montreal, Canada Incinerator

A 1088 metric ton/day (1200 ton/day) plant began operating in 1971 at Montreal

Table 3-9
Typical Incineration Plants With Energy Recovery

LOCATION	DATE OF START UP	STOKER	CAPACITY METRIC TPD / TPD	PARTICLE SEPARATION TECHNIQUE	OUTPUT: FLOW RATE $kg/hr \times 10^{-3}$ / $lb/hr \times 10^{-3}$	OUTPUT: TEMP °C / °F	OUTPUT: PRESSURE $N/m^2 \times 10^{-6}$ / Psig	USAGE	COMMENTS	REFS.
Montreal Canada	1971	Von Roll	4x272 / 4x300	Electric-Static Precipitator	45 / 100	260 / 500	1.55 / 225	Heating & Auxiliary Power	10-15% of input-ash & scrap metal	3-24 3-28
Chicago Northwest Incinerator	1972	Martin	4x363 / 4x400	Electric-Static Precipitator	200 / 440	204 / 400	1.7 / 250	Limited	Recovered Magnetic Metals	3-24 3-28
Harrisburg Pennsylvania	1972	Martin	2x326 / 2x360	Electric-Static Precipitator	63 / 138	232 / 450	1.7 / 250	Auxiliary Power		3-29
Nashville Tennessee	Late 1974	Von Roll	2x226 / 2x360	Wet Scrubbers Dry Cyclone	99 / 218	185 SAT / 365 SAT	1.03 / 150	Auxiliary Coolant, Steam	$16.5 Million	3-30
Saugus Massachusetts	1975	Von Roll	4x272 / 2x360	Electric Static Precipitator	102 / 225	427 / 800	4.3	Power		3-1

(ref. 3-28). The plant's 4 boiler units, using grate technology supplied by Von Roll of Switzerland, generate a total of 4.5×10^4 kilogram/hour (100,000 pound/hour) of steam. The capital cost of the incinerator was $15 million, and the refuse processing cost is estimated at $7.70/metric ton ($7.00/ton), including amortization of capital costs and operating costs. The refuse disposal cost is expected to decrease further once markets are found for all the steam.

The refuse flow is the same as Figure 3-35. The grate itself consists of three distinct sections:

1. a predrying grate,
2. the main incineration area, and
3. a complete burning grate.

The heat transfer equipment includes a radiant section, a convection section, a superheater, and an economizer. The refuse combustion chamber is of ample volume to maintain a satisfactory temperature, without excess heat that might cause the refuse cake to melt. Combustion-chamber temperatures must not exceed 1038°C (1900°F).

A Research-Cottrell electrostatic precipitor is used to remove over 95 percent of the dust entrained by the gases. Each of the four precipitators handles 2830 cubic meters (100,000 cubic feet) per minute of 250°C (482°F) gas on a continuous basis. It will reduce the dust to about 0.17 kilograms/1000kilograms (0.17 pound/1,000 pounds) of gas. This value is below the limits set by the U. S. Federal Incinerator Guidelines.

Although the Montreal Von Roll incinerator was the first on the North American Continent, the design had been used in Europe since 1954. The plant included successive refinements in the art of burning refuse and generating steam simultaneously.

Chicago Northwest Incinerator

A 1451 metric ton/day (1600 ton/day) waterwall incinerator began full-scale operation in 1971 (ref. 3-28). Part of the 199,584 kilogram/hour (440,000 pound/hour) of steam generated is used to operate the plant, with the remainder available for sale. The plant uses European developed Martin stoker system.

The flow diagram for the Chicago Incinerator Plant is shown in Figure 3-35.

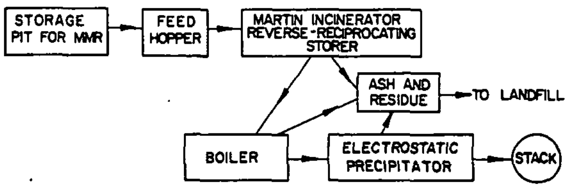


FIGURE 3-35
FLOW DIAGRAM FOR THE
CHICAGO NORTHWEST INCINERATOR

The refuse is taken from the storage pit and fed to the feed hopper. The feed chute has a shut-off gate which is used to prevent air intake to the system during shutdown. The feed chute also automatically feeds refuse into the incinerator.

The main component of the plant is the incinerator, which has a reverse-reciprocating stoker. The stoker grate is inclined at an angle of 26 degrees, developing a normal downward flow of the refuse. The reverse-acting grate pushes the refuse back up the inclined slope, creating a mixing action. Air passes through the grates, supplying oxygen to the refuse which results in maximum burnout in the shortest length of grates.

The Martin Grate Incinerator is designed to make use of the high temperature created in combustion. The combustion gases are directed up over the stoker area toward the incoming refuse, where they dry and help ignite the new refuse.

The combustion gases then pass through the boiler section of the plant. The boiler, approximately 12.2 meters (40 feet) in height, is constructed of membrane water-walled tubes with extruded fins. The use of refractory is limited to a height of 4.6 meters (15 feet) above the grate. This refractory section prevents corrosion of the water-walls when burning plastics. The boiler provides for a maximum amount of heat recovery, and allows for the collection of fly ash. The fly ash collected is automatically fed to the ash discharger where it is mixed with other residue and trucked to a landfill site.

The four incinerator units each handle 363 metric tons (400 tons) of refuse per day, and produce approximately 2×10^5 kilograms (4.4×10^5 pounds) of steam per hour. A portion of the steam is used inplant to drive turbines for pump and blower operation. The balance of the steam is available for sale. Since no market was created initially, most of the steam is condensed in air-cooled condensers.

After the combustion gases have passed through the boiler section they are reduced to a temperature of approximately 232°C (450°F). The gases are then introduced into an electrostatic precipitator which collects the particulate matter still contained in the gas stream, providing a final particulate concentration of 1.14×10^{-4} kilograms/meter^3 (0.05 grains/cubic feet) of gas emitted from the stack. To allow for a high collection efficiency the gas velocity must be less than .91 meter/second (3 feet/second). Once the dust particles have collected on the collector plates, the plates are cleaned automatically by a regular rapping action. The fly ash is then conveyed to the ash discharger.

The capital costs of the Chicago Northwest Incinerator was $23,000,000 in 1970 dollars. The operating cost was estimated at $5/ton at start-up. No sale has been developed for the steam.

Harrisburg, Pennsylvania Incinerator

As Harrisburg's population increased the solid waste problems mounted; consideration was being given to all the available disposal methods, with particular emphasis on a properly engineered sanitary landfill. The search for a new landfill site met with failure; however, it was decided that incineration offered the only dependable, long-range solution to the solid waste problem (ref. 3-29).

The Harrisburg incinerator consists basically of two refuse burning systems, each of which includes a charging hopper and chute, a multi-pass furnace-boiler, a waterwall furnace, an electrostatic precipitator, and the necessary connecting pieces.

In many respects the Harrisburg Incinerator is similar to the Chicago Incinerator, with the flow diagram shown in Figure 3-35. There are, however, some features of the Harrisburg incinerator that are different and will be discussed here.

One such feature is the 45 metric ton (50 ton) capacity weighing station, which is electronically operated to eliminate the need for an attendant. The payload of the vehicle is recorded automatically and a printout is provided that is used to charge for the use of the incinerator.

Another feature of the incinerator is the hammermill shredder that is located below the tipping floor level at the end of the storage pit. The oversized wastes are fed to the shredder through a hopper at the tipping floor level either by handling manually, by dumping from a truck, or by using the overhead cranes. The bulky wastes are reduced to fragments of not more than six inches in any dimension, after which they are conveyed to the storage pit for burning with the other refuse.

The shredder is driven by a 1491 kilowatt (2,000/horsepower) steam turbine. This is a relatively untested method of driving the shredder, which has greatly reduced electric demands of the plant. The performance of the shredding operation has been satisfactory.

To control the air flow through the condenser and subcooler bays, variable pitch fans were used. The pitch of the fans is regulated by inlet conditions to the subcooler and condensate.

Two electrostatic precipitators are used to control the particulate matter in the stack emissions. The precipitators were designed to operate at a gas temperature of 274°C (525°F) and gas velocities not to exceed 1.07 meters (3.5 feet) per second. The average efficiency for the precipitators was tested and determined to be 95 percent.

Nashville, Tennessee Incinerator

The Nashville Thermal Transfer Corporation was chartered under the laws of Tennessee in May, 1970 (ref. 3-30). This tax-exempt corporation was authorized to issue tax exempt revenue bonds, construct, own, and operate the solid waste incineration facility and distribution system in downtown Nashville. The planned incinerator system will cost $16.5 million. The plant will incinerate solid waste and provide the capabilities to heat and cool buildings located in downtown Nashville area.

Plans call for the initial phase of the system to be completed by late 1974, which will include an incinerator capable of burning about 653 metric tons (720 tons) per day of solid waste, and provide heat and chilled water to 27 downtown buildings, 12 of them state office buildings. The incinerator system has production capacity of 1.7×10^{11} joules/hour (13,500 tons) of refrigeration and 99,000 kilograms (218,000 pounds) of steam per hour.

The refuse flow through the incinerator facility is shown in Figure 3-36. The

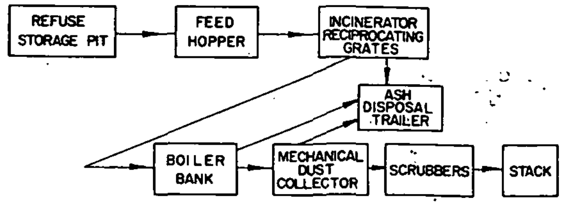


FIGURE 3-36
REFUSE FLOW DIAGRAM FOR THE NASHVILLE INCINERATOR.

solid waste from transfer stations is dumped in the storage pit. The capacity of the pit is 6500 cubic meters (8500 cubic yards), enough storage for four days' operation. Wastes move down the hopper onto a reciprocating type grate for ignition, combustion, and burnout with residue and non-combustibles discharged into the ash disposal trailer. Combustion gases pass through the main boiler bank, mechanical separators and then the three-stage scrubbing system. The system reduces the particulate and gaseous pollutants to the state and federal emission level.

Wet scrubbers will be used so that gaseous pollutants as well as particulates can be removed. The overall emission levels are estimated to be considerably lower than that which would be produced by the many small plants which it replaces.

Saugus, Massachusetts Incinerator

A $31 million plant is being built by Resco, Inc. that will burn garbage and provide steam to the General Electric Plant in Lynn, Massachusetts. The plant will process about 1090 metric tons (1200 tons) of refuse per day, as presented by reference 3-1.

The plant is the United States' largest Von Roll incinerator and should begin operation in 1975. The overall plant is very similar to the Montreal incinerator, and the refuse flow diagram is essentially the same as Figure 3-35. The Saugus incinerator uses a water-wall chamber and inclined grates in the combustion zone. The plant will produce as much as 159,000 kilograms (350,000 pounds) of steam an hour. The steam will be piped across the Saugus River to the General Electric Company at a gage pressure of 4.3 x 10^6 newton/meter^2 (625 psi) and between 418°C (785°F) and 441°C (825°F).

A few special features were included in the design of the plant. It will permit future expansion at both ends. The concrete storage pit will accommodate about 6 times the daily refuse load, 6077 metric tons (6700 tons) in case operations are interrupted. The system will include standby oil burners in the main boilers as well as oil-fired standby boilers to assure continuous steam production.

Fly ash will be controlled with two electrostatic precipitators. Its operations will surpass all environmental requirements, and the plant will neither intake from nor discharge to the Saugus River. A more detailed discussion of the Saugus incinerator will follow in paragraph 3.3.3.1.

3.3.2.1.2 Combustion Power Company's CPU-400 System Energy Conversion System

The CPU-400 system for disposing of municipal refuse is under development by Combustion Power Company. A 63.5 metric ton (70 ton) a day pilot plant has been constructed and is in operation. The system consists of rather complete front-end processing, where magnetic materials, glass, stone, and aluminum are separated. The refuse entering the combustor is the lighter fraction of the air classified stream. See Figure 3-37 for a schematic of the system (ref. 3-31).

The combustor is a fluidized bed, with sand as the heat transfer medium. Combustion gases plus molten aluminum and ash exit the fluidized bed and are cleaned by a series of cyclone separators. These gases are then expanded through a gas turbine/compressor system.

The two-stage turbine drives a compressor, which provides the pressure for the fluidized bed. The second stage of the turbine drives an electrical generator, which provides electrical power as the system output.

Problems have occurred with the gas cleanup, with the fluidized bed, with the rate of refuse feed control, and with aluminum deposits on the turbine blades. The system is still in the development stages, and additional work is being done

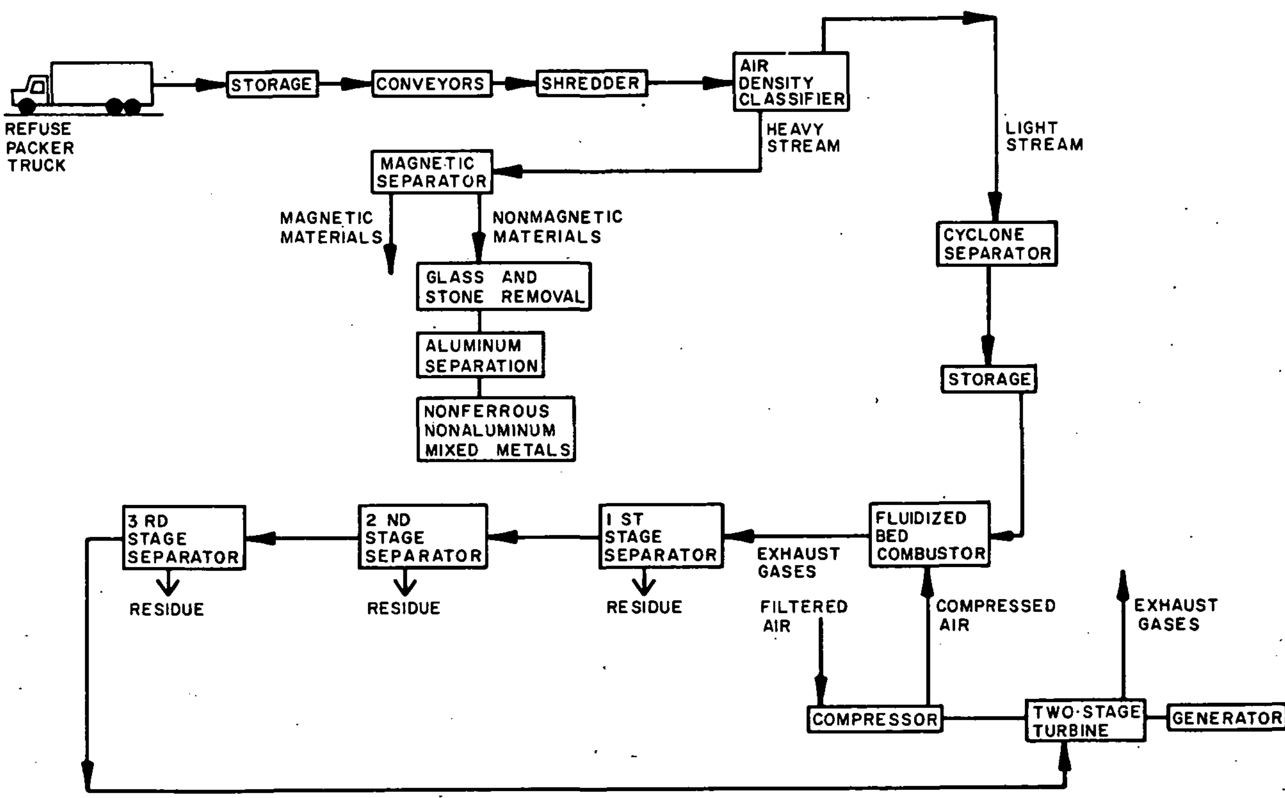


FIGURE 3-37
CPU-400 SYSTEM SCHEMATIC

to improve overall system performance. See paragraph 3.3.3.2 for a more detailed discussion of the CPU-400 process.

3.3.2.2 SUPPLEMENTAL FUEL INCINERATION

Although the practice of recovering energy from the firing of refuse in incinerators or steam-generating boilers is a relatively new concept in the United States, it is a fairly old policy in Europe. A number of refuse-fired plants are in operation throughout the European countries, and three German plants built within the last decade will serve as prototype European plants for the supplemental fuel discussion. The data is taken from Roberts, et.al., (ref. 3-25). Each of these plants has a different means of firing the refuse for energy recovery. Table 3-10 lists representative supplemental fuel plants.

Munich North Plant, Block I

This Munich plant uses refuse as a supplementary fuel with coal, but the burning takes place in two separate chambers. The refuse is fired on a Martin Grate in one chamber, while pulverized coal is fired in the second chamber. A common tube wall separates the two chambers and the combustion gases from both firings combine at the top and pass through the same superheater, economizer, and cleanup equipment.

Capacity of the plant is 599 metric ton/day (660 ton/day) of refuse, which provides approximately 40 percent of the total system heat input. Steam, at a gage pressure of 1.79×10^7 Newton/meter^2 (2600 psig), 540°C (1004°F), at a rate of 9.072×10^4 kilograms (200,000 pounds) per hour is generated. Ferrous metals are separated from the water-quenched residue by magnetic separation. A schematic of the plant operation is shown in Figure 3-38.

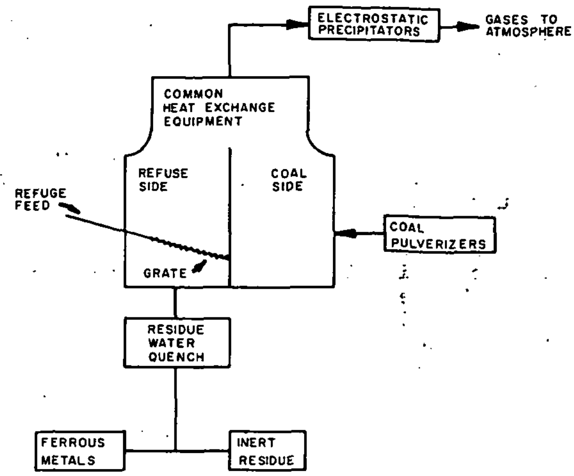


FIGURE 3-38
SCHEMATIC OF MUNICH NORTH PLANT, BLOCK I

Munich North Plant, Block II

This plant differs from the Block I plant in that only one firing chamber is used, with the refuse and coal burned in the same furnace. The pulverized coal is injected pneumatically into the chamber and burns directly over the grate containing the refuse. The refuse firing rate of 961 metric ton/day (1060 ton/day) is almost twice that of the Munich Block I plant, but the refuse input represents only 20 percent of the total heat input.

The steam conditions are the same

TABLE 3-10
REPRESENTATIVE SUPPLEMENTAL FUEL PLANTS

LOCATION	DATE	REFUSE CAPACITY, TON/DAY	METRIC TON/DAY	AUXILIARY FUEL	COMMENTS
MUNICH NORTH I	1965	660	599	COAL	TWO SEPARATE CHAMBERS
STUTTGART	1966	1000	907	OIL	TWO SEPARATE CHAMBERS
MUNICH NORTH II	1967	1060	961	COAL	ONE CHAMBER
ST. LOUIS	1972	2 x 300	2 x 272	COAL	UTILITY BOILER

for the two Munich plants; however, the flow rate of 3.63×10^5 kilograms (800,000 pounds) per hour is proportionally higher for the Block II plant. The heating value of the coal/refuse system is higher because of the smaller percentage of refuse fired, which will yield a higher thermal efficiency. This will account for some of the increased efficiency in the system. The firing configuration apparently is also more efficient.

The common gases again go through the common heat exchange stages and gas cleanup. Ferrous metal is recovered from the quenched residue.

Although the firing is different, the combination burning of coal and refuse in one chamber at a ratio of 20 percent refuse and 80 percent coal (by heating value) is very similar to the St. Louis supplemental fuel project. A schematic of the Block II plant is shown in Figure 3-39.

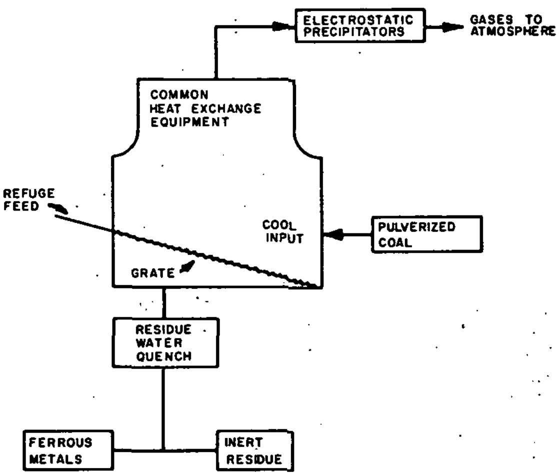


FIGURE 3-39
SCHEMATIC OF MUNICH NORTH PLANT, BLOCK II

Stuttgart Plant

The Stuttgart plant is similar to the Munich North, Block I plant in that two separate chambers are used, each sharing a common tube wall. The Stuttgart plant, however, burns oil in the second chamber instead of coal. The combustion gases from the refuse and the oil enter a common convection chamber and have a common cleanup system.

There are two units at the Stuttgart plant, each firing refuse in one chamber and oil in the other. There is a difference in the grates, however. One is equipped with a Martin grate while the other is equipped with a roller grate.

The steam generation rate for each boiler is 9.28×10^4 kilograms (204,600 pounds) per hour at a gage pressure of 6.37×10^6 newtons/meter^2 (925 psi) and a temperature of 525°C (977°F). The boiler is designed to deliver the required flow rate with refuse only, oil only, or with both oil and refuse. The design refuse firing rate is approximately 18 metric ton/hour (20 ton/hour) on the Martin grate and 20 metric ton/hour (22 ton/hour) on the roller grate.

Fly ash is controlled by an electrostastatic precipitator, and ferrous metal is removed from the cooled residue by magnetic separation.

The overall thermal efficiency of the oil-fired boilers alone approaches 90 percent. If the designed refuse rate is fired with the oil, the thermal of efficiency drops to approximately 70 percent, and would be even lower if the refuse were fired alone. However, the credits associated with the energy derived from the refuse more than offset the loss in overall thermal efficiency.

A schematic of the Stuttgart plant is shown in Figure 3-40.

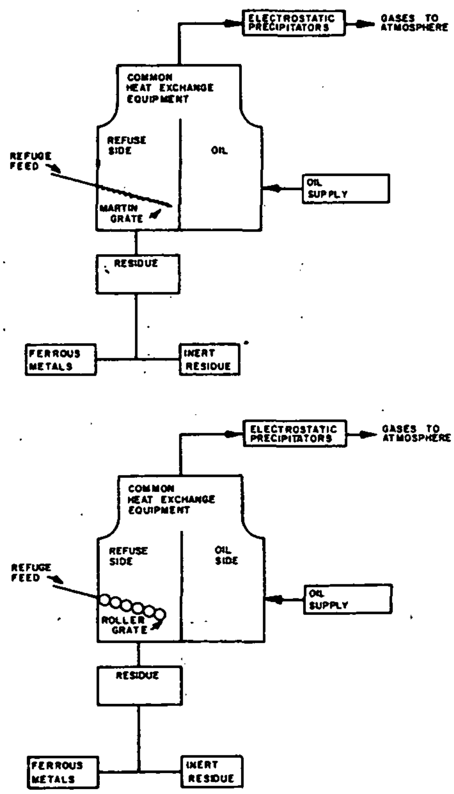


FIGURE 3-40
SCHEMATIC OF STUTTGART PLANT

St. Louis Supplemental Fuel Project

The city of St. Louis, the Union Electric Company, and the EPA started a project in 1972 to burn refuse as a supplemental fuel in one of the St. Louis area power plants. Refuse is shredded, has the magnetic materials removed, and is air classified to remove further the heavy and noncombustible materials. The lighter combustibles, shredded to 3.8 centimeters (1.5 inch) nominal size, are transported from the preparation facility by truck to Union Electric's Meramec Plant.

The prepared refuse is fed pneumatically into the modified boilers, where it is burned in suspension with pulverized coal. Schematics of the supplemental fuel processing and firing facilities are shown in Figures 3-41 and 3-42

Several technical problems have been encountered in the burning of the refuse. They include:

1. Erosion in the piping of the pneumatic conveying system.

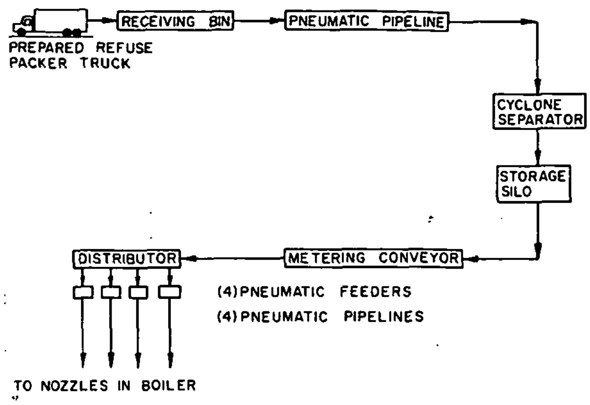


FIGURE 3-42
SCHEMATIC OF REFUSE FIRING FACILITIES AT ST. LOUIS SUPPLEMENTAL FUEL PLANT

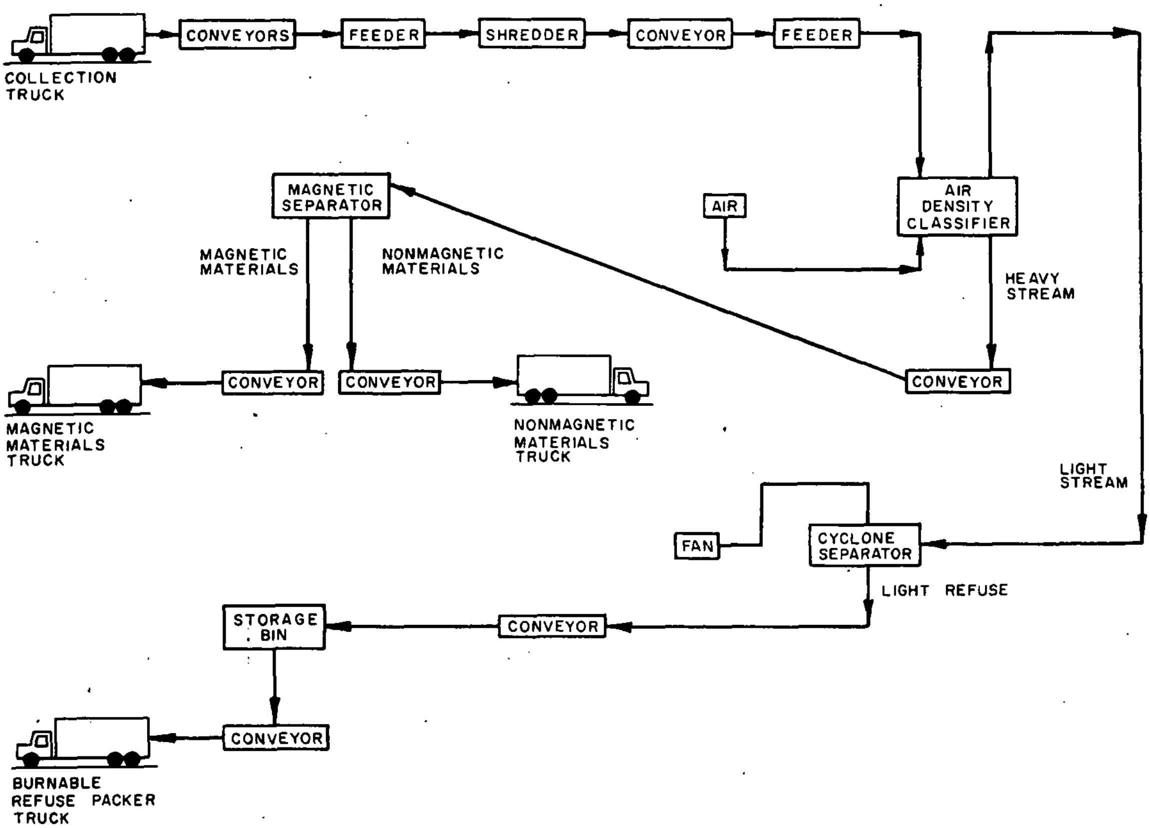


FIGURE 3-41
SCHEMATIC OF PRE-CONVERSION PLANT FOR ST. LOUIS SUPPLEMENTAL FUEL PROJECT

2. Poor combustion of the fuel.

3. Increased bottom ash.

4. Corrosion problems with the pneumatic refuse feeder system.

Addition of a new air classification system in the pre-processing stage is expected to improve the overall system performance and help reduce some of the above technical problems (ref. 3-32). A more detailed discussion of the St. Louis supplemental fuel project is given in paragraph 3.3.3.3.

Future Supplemental Fuel Projects
(Taken from EPA's 2nd Report to Congress reference 3-20)

As mentioned in the EPA's second report to Congress, a number of communities have committed themselves to a policy of burning refuse as a supplemental fuel in conventional boilers. The proposed plans are in various stages of completion, and the following is a description of the planned supplemental fuel projects.

Ames, Iowa - The city is considering using shredded solid waste as a supplemental fuel in a utility boiler. A pre-processing system is expected to be operational in late 1974.

Albany, New York - The city has made a commitment to burn refuse as a supplemental fuel. Market studies are currently underway to determine the potential users for the recovered products and steam. The system is expected to be operational in 1977.

Monroe County, New York - Approximately $9 million dollars have been appropriated by the state of New York as its share of a project to burn refuse as fuel in a Rochester Gas and Electric Utility boiler. Plans are also being made to extract paper for resale in the refuse preconversion stages.

New York, New York - Two projects are already underway in the supplemental fuel area in New York City. One project, in the engineering design stage, is to refit a Consolidated Edison boiler to handle shredded refuse as a supplemental fuel. The other project for which dollars have been appropriated is a feasibility study for the design of a new utility boiler that will burn 50 percent refuse as a solid fuel. The state has appropriated $21 million for its share of the supplemental fuel projects.

Wilmington, Delaware - A cooperative program between the Federal government and the state of Delaware for a resource recovery plant is in the initial design stages. The plant will process municipal sewage sludge. The combustible portion of the refuse will be prepared as a supplemental fuel in an oil-fired boiler or converted to compost, depending on the market. The heavy materials plus selected industrial waste will be pyrolyzed, and the energy from the pyrolysis gases will be used to dry the sewage sludge. Aluminum and glass are expected to be recovered from the pyrolysis residue. Ferrous materials will also be removed by magnetic separation.

The municipal refuse will be shredded initially to a 15.2 - 20.3 centimeter (6 - 8 inch) particle size. This stream will be air classified into a light (mostly combustibles) fraction and a heavy fraction (mostly metals, wood, rocks, etc.). The light fraction will be further shredded to 2.5 to 5 centimeters (1 to 2 inch) particle size and will be used primarily as a supplemental fuel in oil-fired boilers. If a boiler was designed originally to be fired with either coal or oil, there will be both bottom ash handling equipment and particulate control equipment such as electrostatic precipitators.

The system as conceived will process 454 metric tons (500 tons) of municipal refuse, 13.6 metric tons (15 tons) of industrial waste, and 209 metric tons (230 tons) of sewage sludge per day. The plant is expected to be in operation in 1977

Memphis, Tennessee - A 1361 metric ton (1500 ton) per day plant is being proposed at a cost of $8 million, which will produce a supplemental fuel to be fired in steam boilers. The present concept includes a front end system which will separate ferrous metal, aluminum, and glass.

The combustible portion of the refuse will be prepared for firing with coal in a TVA boiler. The savings in coal costs would be approximately $750,000 per year at current energy costs. Another $1 million potentially could be received from the sale of the recovered metal and glass (ref. 3-1).

3.3.3 INCINERATION SYSTEM ALTERNATIVES SELECTED FOR FURTHER ANALYSIS

3.3.3.1 WATER-WALL INCINERATOR - SAUGUS, MASS. FACILITY

3.3.3.1.1 Technical Description

The Saugus plant is being constructed on a site adjacent to the Salem Turnpike just south of theSaugus River. It is designed to burn 1008 metric tons (1200 tons) of refuse daily from 16 communities around Saugus, Massachusetts, with a combined population of about 500,000 (ref. 3-1 and 3-28).

Generally speaking, the refuse-energy plant shown in Figure 3-43 operates in the following manner. Refuse arrives in trucks which proceed first to a weighing area, where they are placed on scales to determine the quantity of incoming refuse. From there, the trucks go to a refuse handling building where the refuse is transferred to a large-capacity storage pit. Bulky objects are fragmented by a hammermill. The air within the refuse handling building is drawn off and used as combustion air, which prevents the escape of odors from the plant.

From the storage pit, refuse is transferred by traveling overhead cranes to the boiler feed hopper. It then goes to the combustion chamber which contains a stair-like grate system. Three inclined, reciprocating grates dry, tumble, and break up the refuse to insure complete combustion.

Combustion temperatures ranging from 871 to 982°C (1600 to 1800°F) consume most of the refuse, as well as odors, within the combustion chamber. Of primary importance, refuse is the only fuel required.

The ash residue, equal to about one-tenth the original refuse volume, is quenched in recycled water. It may be sold for road fill or a construction material.

The Saugus plant output is steam. Refuse-fired steam boilers convert the combustion heat into steam. The steam is used to generate electrical power at a nearby General Electric plant.

Flue gases and fly ash created during combustion are captured during the process. The refuse-fired boilers cool the gases as they produce steam. The gases then flow through electrostatic precipitators, where the particulate matter is removed. The cleaned gases are then released to the atmosphere through the stack.

Plant Description

The Saugus plant is unique in two ways: It is the largest Von Roll refuse burning, steam-generating incinerator to be constructed in this country, and it is privately financed.

The refuse storage pit will have a normal capacity (from the bottom of the pit to the reception area floor) of 2476 metric tons (2730 tons). This amount of refuse will operate the incinerators for approximately 2.3 days. This storage is necessary since the plant will be required to provide steam at times when no refuse is being received. Maximum storage will be 6077 metric tons (6700 tons), enough storage for approximately 5.6 days of

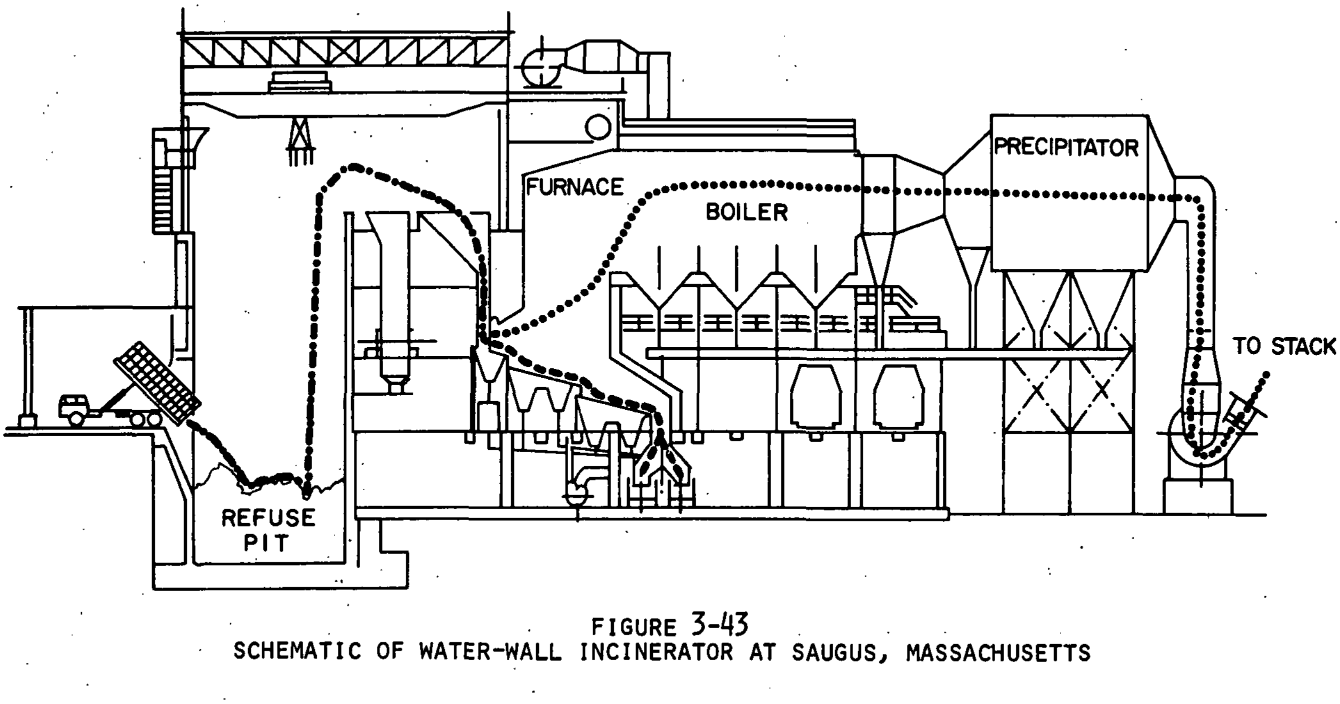


FIGURE 3-43
SCHEMATIC OF WATER-WALL INCINERATOR AT SAUGUS, MASSACHUSETTS

operation.

The building that houses the refuse pit and charging floor also contains a shredder for bulky items and two overhead cranes. The shredder is surrounded by concrete walls for noise suppression. The shredder has a horizontal drive shaft and is equipped with a reversible force feed mechanism. The shredder will have a capacity of 18 to 23 metric tons (20 to 25 tons) per hour. A steam spray system provides fire protection for the shredder.

Two cranes with air-conditioned cabs will lift refuse from the refuse storage pit to the incinerator feed hoppers and will feed bulky items into the shredder. Each crane has a rated capacity of 11.8 metric tons (13 tons). It is anticipated that one crane will operate full time. The refuse building will also house the feed hoppers, furnances, force draft fans, shops, and service area.

Each unit will be equipped with three oil burners. These burners will be used when the refuse does not have sufficient heating value to generate the necessary heat. When operating on No. 6 fuel oil and refuse or on fuel oil alone, the plant can produce 1.81×10^5 kilograms (400,000 pounds) of steam per hour.

The plant is equipped with two electrostatic precipitators. The precipitators were designed to remove particulate matter from the stack gases at an efficiency of 97.5 percent. The stack is 54.3 meters (178 feet) above ground. Ash and dust from the boilers and precipitators are conveyed to the ash conveyors serving the incinerators.

The plant has two 5.4×10^4 kilograms (120,000 pounds) per hour oil fired boilers. These oil fired back-up boilers can generate steam at the same pressure and temperature as the incinerator boilers. The back-up boilers will be used only when the incinerator boilers cannot meet steam demands. These two boilers will have a common stack that is 3 meters (ten feet) above the highest roof in the plant.

A steel bridge across the Saugus River connects the steam generating plant with the General Electric power plant. This bridge will transfer steam to the G. E. plant and condensate, fuel oil, and utility power to the Saugus Plant. The total electrical power requirements for the incineration plant is 3000 kilowatts.

An office building is constructed at the Saugus Plant. This building has a reception area, administrative offices and meeting room. A parking lot for 40 cars is provided at the plant.

Plant Operation

The refuse trucks, upon entering the plant, will be weighed and directed to the unloading area. Two floor-men will weigh and direct trucks to and from the unloading area. Two floor-men will weigh and direct trucks to and from the unloading bays at the edge of the refuse storage pit. The floormen will work one ten hour shift, five days per week. All open trucks will contain mostly bulky materials. These trucks will be directed to the pit area near the shredder.

One of the two cranes will be utilized to load the incinerator hoppers, three shifts per day. The other crane will feed bulky items into the shredder and move refuse in the pit so that the crane that is operated 24 hours per day can reduce its retrieving time.

The refuse in the feed hopper will serve as a seal to the incinerator and prevent flame flashbacks. Should the refuse level in the feed hopper reach the unsafe level, a warning sound will be given the crane operator.

The refuse from the feed hoppers will be fed down onto the grates of each incinerator. As the refuse moves down the first inclined grate, the refuse will be dried and combustion will be initiated. The refuse will then drop, as the result of reciprocating grate motion, onto the second grate, where most of the combustion takes place. The refuse then drops onto the third grate where complete burnout will occur. The ash remaining after burnout and the ash which falls through the grates, will be collected in hoppers that will discharge onto the ash quench conveyor.

Primary combustion air required for combustion will be supplied to the underside of the grates. The air intake will be located in the refuse building. This arrangement will allow offensive odor to be pulled into the incinerator and destroyed.

The incinerators are designed to operate with 100 percent excess air to insure control of the flue gas temperature between 871-1093°C (1600-2000°F). The secondary air required for temperature control is supplied to the furnace above the grate. The secondary air will help complete combustion.

The flue gases upon leaving the furnace will pass through the superheater, generator section and economizer, and then to precipitators. The total steam production is expected to average approximately 1.36×10^5 kilograms (300,000 pounds) per hour. Approximately 6.8×10^3 kilograms (15,000 pounds) per hour will be required for plant auxiliaries at Saugus.

General Electric's Steam Requirements

The General Electric Company has requested that steam be provided at a gage pressure of 4.48×10^6 newton/meter^2 (650 psi) and at a temperature of 441°C (825°F). The steam demand is not constant over a 24 hour period, but varies from a minimum of 9.1×10^4 kilograms/hour (200,000 pounds/hour) to a maximum of 1.8×10^5 kilograms/hour (400,000 pounds/hour). Hourly rates and the percentage of time they are required, as established by General Eelctric, are shown in Table 3-11.

TABLE 3-11
GENERAL ELECTRIC'S STEAM DEMAND FROM THE SAUGUS PLANT

DEMAND KG/HR	DEMAND LB/HR	PERCENT OF TIME
181,440	400,000	5
158,760	350,000	10
136,080	300,000	50
90,720	200,000	35
	TOTAL	100

3.3.3.1.2 Economic Data

The Von Roll waterwall incineration process with steam recovery from the solid waste requires a large amount of capital and has high operating costs. What follows is a cost breakdown of such a process currently under construction at Saugus, Mass. The reported total cost is $31,000,000 for the plant at an operating capacity of about 1090 metric tons (1200 tons) per day.

A cost analysis of the Saugust plant is presented in Table 3-12. The cost estimates were made primarily from two sources. One of which is an EPA report prepared by Metcalf and Eddy, Inc. in 1972, (ref. 3-33). In this report seven alternative options were proposed and evaluated for a plant capacity of either 348 or 555 metric tons of refuse per day (384-612 tons per day). The other source of information is a talk presented by S. E. Stanrod of the Rust Engineering Company at the U. S.: Japan Energy Conservation Seminar in San Antonio, Texas, 1974 (ref. 3-34). All cost estimates are 1975 dollars using the Engineering News Record Index of 1375.

Comment

Some possible reasons that the Saugus plant has a high capital cost are:

1. Construction of a utility bridge across the Saugus River between the plant and the General Electric power plant.

2. There are two back-up boiler units which are used for firing oil only when the supply of refuse is not sufficient to produce the required steam required by General Electric.

3. The plant has a large storage capacity for the refuse, and has room for expansion to handle up to 2180 metric tons (2400 tons).

TABLE 3-12
COST DATA ON SAUGUS, MASS., WATER-WALL INCINERATOR
COST ANALYSIS

Assumptions:
- Average Daily Refuse Burned:
  - 1092 Metric tons (1200tpd)
- Average Annual Refuse Burned:
  - 382,200 metric tons (420,000 tons) (350 days of 24 hours each)
- Steam Generation from Refuse Only:
  - 1129 million kilograms (2486.4 million lbs.)
- Net Steam Production per Year:
  - 1072 million kilograms (2362 million lbs.) (5% of the steam is used in plant)
- Steam is sold to General Electric at
  - $1.50 per 454 kilograms ($1.50 per 1000lbs.)
- Financing is private with:
  - 70% debt at rate of 8%
  - 30% equity at rate of 20%
- Plant life: 20 years

Annual capital recovery factor at effective rate of: (8%)(.70) + (20%)(.30) = 11.6% is 0.133

Annual Cost:

Capital (0.133)(30,417,000) =	4,055,460
operating (exclude interest)	1,855,000
Total Annual Cost	$5,910,460

Gross Annual Cost - Annual Revenue = Net Annual Cost
At Steam Price of $1.50 per 454 kilograms ($1.50/1000 lbs): $2,367,460

Gross Cost per ton of Refuse = (5,910,460)/(420,000) = $15.50/metric ton ($14.07/ton)

Net Cost per ton of Refuse = $6.16/metric ton ($5.59/ton)

TABLE 3-12 (CONTINUED)

PROCESS NAME: Saugus Waterwall Incineration Plant
DATA SOURCE: References 3-33 and 3-34
CAPACITY IN TONS/DAY: 1092 metric tons (1200 tpd)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land	Not available	All estimates based on ENR Index 1375 (100 for the year of 1921), and included 10% allowance for general conditions.
Preprocessing Eqmt.	$ 1,310,000	
Processing Eqmt	13,390,000	
Postprocessing Eqmt	85,000	
Utilities	1,438,000	
Building & Roads	4,701,000	Detail estimates, given by Metcalf & Eddy, Inc. for a 350 metric tons per day boiler plant (385 tpd), were used.
Site Preparation	1,375,000	
Engr. & R & D	5,608,000	
Plant Startup	Included	
Working Capital	1,000,000	
Misc.: Crossing bridge	1,375,000	
Others	123,000	
TOTAL	$30,417,000	
OPERATING COSTS ($ PER YR.)		
Maint. Material	$ 144,000	(1) Assume credits from scrap metals and other materials will pay for the disposal of residues.
Maint. Labor	69,000	
Dir. Labor	478,000	
Dir. Materials	78,000	
Overhead	143,000	
Utilities	345,000	(2) Fuel cost is not considered because: a) quantity needed will depend on the shortage of refuse, and b) credit from steam generated when burning fuel oil will not be considered either.
Taxes 1½% of fixed capt.	451,000	
Insurance ½% of capt.	147,000	
Interest	1,703,000 (3)	
Disposal of Residue	(1)	
Payroll Benefits	Not available	
Fuel	(2)	
Misc.:		
TOTAL	$ 3,558,000	(3) Assume 70% debt at 8% rate, and 30% equity at 20% rate. Thus the interest paid annually is (8%)(70%)($30,417,000)= $1,703,000
CREDITS ASSUMED ($ PER YR.)	$ 3,543,000	see "Resource Recovery Data"
Fuel:		Steam production at 1200 tpd, 134,000 kilograms/hr (296,000 lbs/hr) or 1129 million kilograms/yr (2486.4 million lbs/yr)
Liquid		
Gas		
Solid		
Power:		
Steam	$ 3,543,000	
Electricity		5% of the steam is consumed in plant.
Hot Water		
Magnetic Metals		
Nonmagnetic Metals		Net steam production: 1072 million kilograms/yr. (2362 million lbs/yr)
Glass		
Ash		
Paper		
Other:		Sold to General Electric at $1.50 kilograms ($1.50 per 1000 lbs), the net revenue of steam is estimated at $3,543,000 annually.
TOTAL ($ PER YR.)	$ 3,543,000	

3.3.3.2 CPU-400 ENERGY CONVERSION SYSTEM

3.3.3.2.1 Technical Description

The CPU-400 is a solid waste disposal system which converts the energy in the refuse to electrical power. The system uses a fluidized bed incinerator as the combustor and a gas turbine-generator to produce the electrical power. The CPU-400 process has been demonstrated by a pilot plant with a capacity of 63.5 metric ton/day (70 ton/per day). A schematic of the CPU-400 process is shown in Figure 3-37. The prototype plant would be of modular design, each unit having a capacity of approximately 136 metric ton/day (150 ton/day). The following is a brief description of the CPU-400 system as discussed in references 3-2, 3-31, 3-35, 3-36, and 3-37.

Pre-Processing

Incoming packer trucks deposit the refuse in the receiving area where front end loaders push it to the shredder conveyors. The shredders will be sized to handle a greater capacity of refuse than will normally be required in the system operation, so this gives a redundant feature to the shredding process. The shredders are a vertical axis type, with the prototype plant expected to use two 74.6 killowatts (100 horsepower) shredders for each combustor module.

The shredded material is then conveyed to an air density separator, where the heavy and light materials are separated. Typically, the lighter fraction is 83 percent of the refuse stream and consists of the light combustibles plus about 15 percent inert materials, such as metal foil and sand. The heavy stream contains about 25 percent combustibles along with the inert material and metals.

The light stream is conveyed pneumatically to the storage bin. Two cyclones separate the dust-laden air from the refuse, which is stored until ready for the combustor.

The heavy fraction is then processed for removal of the saleable materials. A magnetic separator removes the magnetic materials (primarily ferrous); glass and stone are then removed, so the final stream ideally should consist of aluminum and other metals. Aluminum is removed for sale, and the remaining metals may also be sold. The aluminum is separated by a newly developed process using dry electromagnetic separators.

Power Generation System

Fluidized bed combustor -- The combustor in the system is a pressurized, fluidized bed using sand as the heat transfer medium. Auxiliary oil is burned initially to heat the sand, but the combustion process sustains itself once the bed is heated. The prepared refuse is pneumatically fed into the combustor, where the sand is in suspension from the buoyant effects of the compressor air. The temperature within the bed is approximately 761°C (1400°F).

The combustor is a vertical shaft bed, 6.7 meters (22 feet) high and approximately 2.4 meters (7 feet) inside diameter. The combustion area itself is lined with firebrick, and Kawool insulation separates the firebrick from the sides of the vessel. The starter bed is of 16 mesh sand and is 0.6 meter (2 feet) deep.

Particle separators -- Since the gas stream contains particles of sand as well as ash and other particulates, a rigorous cleanup system must be employed before the gas can be expanded through the turbine. The pilot plant has three particle separators, and it is assumed that the prototype plant will also have to employ a similar cleanup system.

The first separator is designed to remove the larger particles of sand and aluminum, plus some ash. Some of the aluminum is in the molten condition, and some care has to be taken to prevent the aluminum particles from impinging on the sides of the cyclone separator and forming an aluminum oxide deposit. The first separator is approximately 2.4 meters (7 feet) in diameter.

The second and third cyclone separators are designed for removal of the ash and smaller particles in the gas stream. There are 48 tubes, 15 centimeters (6 inches) in diameter, in the second separator and 100 tubes, 9 centimeters (3½ inches) in diameter in the third. Both separators empty into a common ash hopper, and pneumatic vibrators are used to keep the ash flowing into the hopper.

The clean-up stages are very critical to correct operation of the CPU-400 system. The maximum particle size entering the turbine should be much less than 5 microns to prevent erosion of the turbine blades. Performance curves given in Chapman and Wocasek (ref. 3-31) indicate that the cyclone separators are capable of removing the larger particles, but plugging of the tubes has been a problem during model testing. Assuming the cyclone separators perform as designed, the expected turbine blade life would be a minimum of two years.

Turbine-Generator Subsystem -- This subsystem consists primarily of the turbine-compressor and electrical power generator. Cleaned air from the combustor enters the gas turbine at a temperature of approximately 761°C (1400°F). The energy derived from the gas in expanding through the turbine drives a compressor, which provides the pressurized air for the fluidized bed combustor. The pilot plant uses a two-stage gas turbine, with the second stage driving the 1000 killowatt generator. The pilot plant operates at a gage pressure of 2.55 x 10^5 newton/meter^2 (37 psig) while the prototype units are scheduled for a gage pressure of 9 x 10^5 newtons/meter^2 (130 psig) operation. This higher pressure should increase the operating efficiency and the electrical output per ton of refuse incinerated.

Automatic Control System -- The CPU-400 employs a process control computer for controlling the refuse feed throughout the system. Precise incineration control is required to maintain the turbine inlet temperature within specified limits. Manual control of the system is also provided. The process computer also contains a mass data unit for storage of data and various input-output devices and subsystems.

Pilot Plant System Performance -- Extensive testing has been conducted on the fluidized bed by itself, and separate testing has been conducted on the turbine-generator system using auxiliary air. The pilot plant, however, has been operated as a complete system only for limited periods of time.

At startup, auxiliary oil is burned to bring the system up to temperature. The turbine combustor is also fired using diesel oil, and the turbine-generator system is operated separately and brought up nearly to full power on the auxiliary system. Air from the compressor is then diverted into the fluidized bed. The whole system is then stabilized at operating temperature, pressure, and power output before switching over to the fluidized bed operation. The system startup requires approximately five hours.

The pilot plant was operated for a short period (48 hours) at low pressure during the acceptance test, but no power was generated. During the acceptance test the incinerator system was controlled automatically and operated within 17°C (30°F) of the selected temperature. The combustion efficiency was greater than 99 percent. The solid waste feed rate during the test was 18.6 kilograms (41 pounds) per minute. A typical high pressure test with 45.4 kilograms (100 pounds) per minute of refuse is expected to generate approximately 1000 kilowatts of electrical power.

Technical Evaluation of CPU-400 Process

The CPU-400 system is an advanced concept for solid waste disposal and energy recovery. The basic principles behind the system are sound--a good front-end processing system for materials recovery and efficient material classification, a high heat transfer combustor in the fluidized bed, and a saleable end product, electricity. The system is fully automated for good process control and produces few pollutants.

Unfortunately, the system to date has not performed as expected. The original design of the fluidized bed was poor and had to be redesigned. The gas cleanup system has to remove particulates to standards far more stringent than EPA requirements for proper operation of the turbine, and the cleanup must be accomplished at high temperatures. The gas cleanup levels required are beyond the current state of the art in cyclone separators, both for the particulates and for the molten aluminum in the gas stream. The molten aluminum eventually solidifies as aluminum oxide and causes these solid deposits throughout the system. Deposits on the turbine blades can also cause a decrease in operating life of the turbine. More developmental work is required on the gas cleanup system, and it is possible that the stream cannot be cleaned sufficiently for sustained operation of the turbine. (ref. 3-31)

Another potential problem area is the fluidized bed combustor. Although the technology of fluidized beds is well known from the petrochemical industry, there is a very basic difference in the consistency of the feed. The output from municipal refuse, even after shredding and air classification, is a heterogeneous mixture of paper, aluminum, cardboard, and other light substances. This fact could lead to problems in maintaining the fluid nature of the bed. If proper operating temperatures and velocities within the bed are not maintained, large "chunks" could be formed in the bed, and ultimately the bed itself could solidify. (ref. 3-31)

As pointed out by Schulz (ref. 3-21) generating electrical power on site escalates the capital costs and requires a balanced operation of two unrelated functions - refuse incineration and electrical power generation. A high pressure fluidized bed is also a complicating factor.

In summary, the CPU-400 pilot plant to date has not demonstrated sufficient overall system reliability to justify building a prototype plant.

3.3.3.2.2 Economic Data for CPU-400 System

The three sources of data used here concerning the C.P.U. process are Chapman and Wocasek, (ref. 3-31) Schulz et.al. (ref. 3-21), and Midwest Research Institute Report (ref. 3-28).

The data presented from reference 3-31 are shown in Table 3-13 and are based on a presumed 544 metric ton/day (600 ton/day), 3 power module CPU system. It is assumed that the electric power gives a credit of 8 mills per kilowatt hour. Here the economics of considering the CPU 400 for handling MMR is possibly distorted by crediting it for handling sewage solids. In the economic data, the process is given a large credit for sewage sludge disposal.

The data presented from the Midwest Research Institute Report are based on a 907 metric ton/day (1000 ton/day) 365 days per year system. It is assumed that the electric power gives a credit of 6.5 mills per kilowatt hour.

3.3.3.3 ST. LOUIS SUPPLEMENTAL FUEL

3.3.3.3.1 Technical Description

After a thorough review of the existing boiler facilities owned and operated by the Union Electric Company in the St. Louis area, Horner and Shifrin, Inc., Consulting Engineers, recommended modification of two of the existing boilers at the Meramec Plant. The facility uses coal burning boilers, each equipped with four coal pulverizers with a capacity of 1.88×10^4 kilograms/hour (41,500 pounds/hour). The coal is fed to the 30.48 centimeter (12 inch) burners by a rotary-type coal feeder.

Each boiler had to be modified to accommodate the refuse, which was shredded to a size of 2.54 to 5.08 centimeters (1 to 2 inches). Refer to Figure 3-42 for the refuse firing system schematic. The Meramec plant was equipped to burn natural gas, so the natural gas burners were modified to accept the prepared refuse. Pneumatic conveyers are used to blow the refuse into the boiler, where it is burned in suspension with the coal.

Technical Implications of Burning Refuse

Corrosion - The potential corrosive effects of burning refuse in a boiler is known, and the modified boiler has not been in operation long enough for a full evaluation. Experience from pure incineration shows that the burning of refuse is potentially more corrosive than the burning of fossil fuels. Polyvinyl chloride (PVC) is one of the possible constituents of refuse that could be extremely corrosive. The results of a PVC corrosion investigation in incinerators is summarized by Vaughan, et.al. (ref. 3-38) and is also discussed in Roberts, Sommerlad, et.al., (ref. 3-25). One of the final recommendations by Vaughan was that metal temperatures be kept less than 204°C (400°F), which will not be possible in the energy recovery systems. Long term tests will be required to assess fully the impact of the corrosion caused by PVC, because the rate of corrosion is apparently not a linear function of PVC content or temperature; further, the rate of corrosion decreases with time. This means that short term corrosion tests cannot be extrapolated with any degree of accuracy to determine long-term corrosion. Vaughan also discusses the corrosive resistance of several different types of stainless steel, some of which are much less susceptible to corrosion caused by PVC content in refuse. European incinerators have been burning refuse for years with no appreciable corrosion experienced, although the PVC content in the refuse is probably less than the U.S., on the average. Since the refuse is burned with the coal in St. Louis, the detrimental corrosive effects should be less. Additional information on corrosion is included in Astrom, (ref. 3-24, and Fernandes and Shenk (ref. 3-39).

Another potential problem involves hydrochloric acid (HCl). If hydrogen chloride reacts with water, either in water-quenching systems or in systems where the gas is allowed to cool down below the dew point of water, then hydrochloric acid will be formed. This acid is highly reactive and will be extremely corrosive to the structural steel and pipes in the system. Other polymeric materials could also contribute harmful corrosive gases in the incineration process. If electrostatic precipitators only are used and if the gas temperature is kept above 177°C (350°F) the HCl acid attack will not be a problem. This point is discussed in Aubin (ref. 3-40).

Pollution - The Union Electric plant was already equipped with pollution control devices - electrostatic precipitators, for particulate removal. Although more particulates will probably result from the supplemental burning of refuse, the total impact is not known at this time. Both particulate and gas emission tests were run by the EPA in late 1973, and the preliminary results did not disclose any serious problems. The results are reported by Sutterfield (ref. 3-41). While the refuse may contribute to additional particulates, the amount of gaseous po pollutants could be reduced from the refuse as a fuel. Consider SO_x, for example. The amount of sulphur present in the coal burned in St. Louis sometimes exceeds 2 percent. This contributes greatly to the amount of SO_x pollution. The amount of

TABLE 3-13 (A)
ECONOMIC DATA - CPU-400 SYSTEM
PROCESS COST SHEET

PROCESS NAME: CPU-400 with Material Recovery
DATA SOURCE: Reference 3-31
CAPACITY IN TONS/DAY: 544 Metric tons (600tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt	$ 700,000	Material Recovery
Processing Eqmt		
Postprocessing Eqmt		
Utilities		
Building & Roads		
Site Preparation	8,400,000	
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	$9,100,000	
OPERATING COSTS ($ PER YR)		
Maint. Material		
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead		
Utilities		
Taxes		
Insurance		
Interest		
Disposal of Residue		
Payroll Benefits		
Fuel	$ 880,000	Operating costs without Material recovery
Misc.:	100,000	Material recovery Operating costs
TOTAL	$ 980,000	
CREDITS ASSUMED ($ PER YR)	$1,650,000	

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam		
Electricity	$ 760,000	
Hot Water		
Magnetic Metals	340,000	
Nonmagnetic Metals	320,000	Aluminum 200,000 Other $120,000
Glass	90,000	Glass, includes sand
Ash		
Paper		
Other:	140,000	Sewage sludge credit
TOTAL ($ PER YR.)	$1,650,000	

TABLE 3-13 (B)

PROCESS NAME: CPU-400 Without Matérial Recovery

DATA SOURCE: Reference 3-31

CAPACITY IN TONS/DAY: 544 Metric tons (600 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities		
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	$8,400,000	
OPERATING COSTS ($ PER YR)		Sewage Sludge Disposal Credit: A population generating 179,000 metric tons/yr (197,000 ton/yr) of solid waste will generage about 5079 metric tons per year of sewage solids. (5600 tons) Income @ $28/dry metric ton of sewage solids is $140,000. Electrical Income Credit: 95 x 10^6 kw.hr./yr. @ 8 mills/kw.hr.
Maint. Material	$ 400,000	
Maint. Labor	400,000	
Dir. Labor		
Dir. Materials		
Overhead		
Utilities	80,000	
Taxes		
Insurance		
Interest		
Disposal of Residue		
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	$ 880,000	
CREDITS ASSUMED ($ PER YR)	$ 140,000 760,000	Sludge Disposal Credit Electrical Income
TOTAL	$ 900,000	

TABLE 3-13 (c)

PROCESS NAME: CPU-400
DATA SOURCE: Reference 3-28
CAPACITY IN TONS/DAY: 907 metric tons/day (1000 ton/day) 365 days/yr.)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities		
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	$9,306,000	With materials recovery
OPERATING COSTS ($ PER YR)		
Maint. Material		
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead		
Utilities		
Taxes		
Insurance		
Interest		
Disposal of Residue		
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	$1,176,000	
CREDITS ASSUMED ($ PER YR)	$2,106,000	

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam		
Electricity	$1,007,000	
Hot Water	256,000	
Magnetic Metals	548,000	Aluminum: $365,000; Other: $183,000
Nonmagnetic Metals		
Glass	131,000	
Ash	164,000	Includes sand
Paper		
Other:		
TOTAL ($ PER YR.)	$2,106,000	

TABLE 3-13 (D)

PROCESS NAME: CPU-400
DATA SOURCE: Reference 3-21
CAPACITY IN TONS/DAY: 907 metric ton/day (1000 ton/day)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities		
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	$17,000,000	
OPERATING COSTS ($ PER YR)		Refuse Preparation
Maint. Material		365 x 1000 x 4.43 =
Maint. Labor		$1,616,950
Dir. Labor		Combustion Process
Dir. Materials		365 x 1000 x 3.53 =
Overhead		$1,288,450
Utilities		Materials Recovery
Taxes		365 x 1000 x 1.10 =
Insurance		$401,500
Interest		Disposal of Residue
Disposal of Residue	$ 255,500	365 x 1000 x .70 =
Payroll Benefits		$255,500
Fuel		
Misc.: Other	3,306,900	TOTAL: $3,562,400
TOTAL	$ 3,562,400	
CREDITS ASSUMED ($ PER YR)	$ 1,697,250	

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam		
Electricity	$1,368,750	365 x 1000 x 3.75
Hot Water	255,500	365 x 1000 x .70
Magnetic Metals		
Nonmagnetic Metals		
Glass	63,999	365 x 1000 x .20 (Glass or Vitreous Frit)
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	$1,697,250	

sulphur in refuse is extremely small, with a maximum content usually considered 0.2 percent (ref. 3-42). Burning refuse with coal, therefore, should reduce the overall SO_x stack emissions. The highly variable nature of refuse makes it difficult to predict the additional amounts of CO and NO_x that will result, but if good combustion is achieved in the boiler, then the resulting CO and NO_x emissions should not differ greatly from that of burning coal only. There are no emission standards at present for HCl and some of the other gases which may result from burning refuse, and some further consideration should be given to these possible pollutants.

Ash Content - The content of both the fly ash and the bottom ash will change as a result of burning refuse as a supplemental fuel. The refuse will probably contain some non-combustibles which will drop through unburned. The amount of bottom ash has increased the volume of residue, but the facilities are adequate to handle the increase. Better burning is now achieved since the air density classifier has been added to the refuse processing.

The fly ash is collected by electrostatic precipitators and sold to a cement manufacturer. The firing of the refuse with the coal has not changed the quality of the ash substantially, and it is still being sold to the cement manufacturer.

The coal bottom ash was previously used by the Missouri State Highway Department on snow-covered roads. The burning of refuse has changed the bottom ash, as it now contains large amounts of unburned wood, metal, and other particles. The bottom ash is now unacceptable for application on roads. The air classification system which has been added at the refuse processing station is expected to improve the overall combustion in the boiler and reduce the amount of unburned materials in the bottom ash.

Erosion Effects - One of the biggest problems encountered in the handling of the refuse has been the erosion or abrasion of the pneumatic pipes carrying the refuse to the boilers. The abrasion has been particularly bad in the pipe turns and elbows. The transfer pipes are made of mild steel, and this problem could apparently be corrected by installing stainless stell elbows and pipes. To date, however, the replacement pipes have apparently also been mild steel, according to Sutterfield (ref. 3-41).

A very good reference on the St. Louis project is included in an EPA report by Lowe (ref. 3-43).

Refuse Processing

The refuse is processed at a facility several miles from the Meramec plant and transported by truck to the power plant. A number of changes and modifications have been made since the initial installation, the most notable being the addition of an air density classifier. The processing described herein is the plant operation as the beginning of 1974.

The schematic of the pre-conversion plant is shown in Figure 3-41. The raw refuse from packer trucks is discharged in the refuse receiving building, where front-end loaders push the refuse to a receiving belt conveyor. The receiving conveyor has a variable speed to control the rate of feed to the shredder.

The refuse is dropped to a feeder where it is shredded by a hammermill to a nominal 3.8 centimeter (1½ inch) size. After shredding the refuse is now conveyed to a surge bin, which controls the rate of feed to the air density separator (ADS). The ADS was added to separate the lighter, combustible material from the heavier fraction since only the lighter fraction will go to the boiler to be burned, this will improve the overall burning characteristics of the supplemental fuel and reduce the amount of bottom ash and residue. The pipe wear problem should also decrease somewhat and the air classification should provide better pneumatic transport of the fuel.

The heavy fraction is now conveyed to a magnetic separator to separate the magnetic and non-magnetic materials. At the present time the magnetic materials are sold, and the non-magnetic residue is land-filled.

The lighter refuse and conveying air are now run through a cyclone separator which separates the two. The refuse drops to a conveyor, where it is conveyed to a storage bin. The air is discharged to the atmosphere.

The refuse is unloaded from the storage bin by means of a twin screw unloader. Large packer trucks then transport the shredded and air classified refuse to the Meramec power plant.

Technical Evaluation

The firing of prepared refuse as a supplemental fuel in a coal-fired boiler has only been a partial success to date. The original concept of 272 metric ton/day (300 ton/day) of refuse has currently been reduced to 181 metric ton/day (200 ton/day) and this latter amount has not been sustained for a long period of time. Some of the problems have been attributed to the front-end or pre-conversion system, while other problems have been with the firing facility itself. Exhaustive environmental tests have not yet been conducted; therefore, the environmental impact has not been fully evaluated. Specific problems at the processing plant are discussed by Sutterfield (ref. 3-41) and include everything from conveyor belt problems to housekeeping problems. The type of problems encountered have caused excessive delays and a great deal of down time, but the problems are not insurmountable from the technological viewpoint. They represent typical problems which might be encountered in start-up of any complex plant.

The problems at the firing facility have been connected primarily with the pneumatic transport of the prepared refuse. Problems with the air lock mechanism and erosion of the pipes, particularly in the elbows and turning sections, have caused some down time. The air lock problems have been greatly reduced by the addition of the air density separation system at the refuse processing plant, and the pipe erosion could be reduced by abrasion-resistant pipes. The problems, again, are not technologically insurmountable. As mentioned earlier, the environmental impact has not been fully determined, but present technology is sufficient to clean up the exhaust gases, if the existing system is not adequate.

As discussed in Schulz, et.al. (ref. 3-21) the use of prepared refuse as a supplemental fuel is a viable method of energy recovery and refuse disposal in coal fired boilers. Gas or oil-fired boilers would have to be modified at considerable capital expense to add bottom ash handling facilities and emission control devices. Although the cost of the supplemental fuel varies from location to location, depending on local energy credits and the value of the recovered resources, supplemental fuel incineration in coal-fired boilers is one of the cheapest methods of refuse disposal, competing quite favorably with cheap landfill disposal.

3.3.3.3.2 Economic Analysis

The Horner Shifrin supplementary fuel process is one of the conversion processes requiring a small capital investment per daily ton of capacity; this is on the order of $7000 - $8000 per daily ton. The capital investment only requires some relatively minor modifications to existing boilers, so that they may accept prepared refuse for burning along with some other fuel, usually coal. As will be seen later, the estimated cost per ton for this process is one of the lowest of all processes considered in this report.

This section presents Process Cost Sheets for all data sources used. A net cost per ton has been computed for each process configuration. These sources do provide a very good estimate for the costs of a Horner-Shifrin type process. One should nevertheless be careful when studying the data reproduced in this section since all data sources use different assumptions. For example, some sources consider the costs of residue disposal, while others do not. Some sources use cost data in 1969 dollars while others have them in 1972 dollars. There are many other assumptions that differ from source to source, but the most important of these are summarized in the pages that follow.

Comments on Table 3-14

The cost data given in the following Process Cost Sheets are estimated costs for the Horner-Shifrin Supplementary fuel process as applied to the St. Louis, Missouri, metropolitan area. The source for this data is an EPA report prepared by Horner and Shifrin (ref. 3-32).

The following are cost parameters which were used in reference 3-32.

Interest rate, %	5
Useful life assumed, years	20
Land Costs, $/acre	Not specified
Heating value of refuse	$1.2 \times 10^{10} \frac{\text{joules}}{\text{metric ton}}$ ($10 \times 10^6 \frac{\text{Btu}}{\text{ton}}$)
Residue disposal costs, $/ton	Not considered
Waste residues to be landfilled, % of input refuse	Not considered
Net credit given for recovery of metal $/ton	Not considered
Recovery rate for metal, % of input	Not considered
Net credit for use of waste as supp. fuel.	$0.285/10^9 joules ($0.30/10^6 Btu)
Fraction of input refuse that is converted to suppl. fuel	.9245

This report assumes that the processing plant will be within 25 miles of the power plants where refuse will be burned as supplementary fuel.

This study was made assuming that the milled refuse, particle size of approximately 2.54 centimeter (1 inch), would replace approximately 10% of the heat value of the pulverized coal used in suspension-fired boilers.

Since in this report cost estimates are given for various configurations ranging in capacity between 444 metric ton/day (490 ton/day) and 1333 metric ton/day (1470 ton/day), the above comments will not be repeated for all those Process Cost Sheets which were obtained under the same assumptions. For computations on the net cost/ton for all of the configurations please refer to the discussion following all the Process Cost and Resource Recovery sheets.

Comments on Table 3-15

The Midwest Research Institute Report of February, 1973, titled Resource Recovery: The State of Technology (ref. 3-2), performed an economic analysis of fuel recovery systems such as the Horner-Shifrin process. Although the report contains a detailed explanation of the assumptions made in the development of their costs, the most important of these are summarized below:

The following are cost parameters which were used in this report (ref. 3-2):

Interest rate, %	5%
Useful life assumed, years	20
Land Costs, $/acre	Not specified
Heating value of refuse, BTU/ton	NS
Waste residues to be landfilled, % of input refuse	NS
Net Credit given for recovery of metal	$13.23/metric ton ($12/ton)
Recovery rate for metal, % of input	6.8%
Net credit for use of waste as supp. fuel	$\$0.237/10^9$ joules ($\$0.25/10^6$ Btu)
Fraction of input refuse that is converted to suppl. fuel	NS

This report does not give the approximate distance between the refuse processing plant and the utility company which will use the prepared refuse as supplementary fuel. It is assumed, however, in the report, that refuse, as supplementary fuel, would likely not be more than 10 to 15 percent of a utility's requirement.

The Midwest Research Institute Report is based on a municipally-owned and operated facility which operates 300 days per year and 24 hours per day. Although a 907 metric ton (1000 ton) per day plant was used as the basis for the economic analysis, scale factors were developed for each major system component thus enabling investments, costs, and revenues to be projected for facilities with daily capacities of 227 (250), 454(500), and 1814 (2000) tons.

It should be indicated here that this source amortized what they refer to as "Amortized Investment" (Engineering R & D, and Plant Startup Capital Costs) at 5% over 5 years. It would have been more desirable to spread this investment over the 20 year useful life at 5% and not over 5 years, since this would better reflect the true equivalent annual costs.

Comments on Table 3-16

The following report by Schulz (ref. 3-21) computes costs for a Horner-Shifrin 1406 metric ton (1550 ton/per day) plant in New York City.

Transportation costs or distances are not given in this report. It is assumed that the prepared fefuse, burned in suspension - fired utility boilers will supply 10 to 20 percent of the total fuel requirements at the boiler installation. The plant is assumed to be in operation 365 days/year.

The following are cost parameters which were used in this report:

Interest rate, %	6.5
Useful life assumed, years	15
Land Costs, $/acre	Not specified
Heating value of refuse	$9.06 \times 10^9 \frac{\text{joules}}{\text{metric ton}}$ $7.8 \times 10^6 \frac{\text{Btu}}{\text{Ton}}$
Residue disposal costs	$5.51/metric ton ($5/ton)
Waste residues to be landfilled, % of input refuse	20

TABLE 3-14 (A)
ECONOMIC DATA-ST. LOUIS SUPPLEMENTAL FUEL SYSTEM (REF. 3-32)
PROCESS COST SHEET

PROCESS NAME: Horner-Shifrin Supplementary Fuel
DATA SOURCE: Reference 3-32
CAPACITY IN TONS/DAY: 444 metric tons (490 TPD) per day (one shift, one processing unit)

	DOLLARS 115,552 metric tons (127,400 TPY) Operating 5 days/wk	COMMENTS 138,590 metric tons (152,800 TPY) Operating 6 days/wk
CAPITAL COSTS (TOT. $)		
Land	$ 150,000	
Preprocessing Eqmt	277,000	
Processing Eqmt	1,743,000	
Postprocessing Eqmt	Not specified	
Utilities	NS	
Building & Roads	886,000	
Site Preparation	39,000	
Engr. & R & D	252,000	Assumes:
Plant Startup	NS	*Financing by means of general obligation bonds, with
Working Capital	NS	a 20 year term, and an annual
Misc.: Landfill Site	125,000	interest rate of 5%
Construction Contingencies	281,500	
Escalation to 1973 Costs	811,500	
TOTAL	$4,565,000	$4,565,000
OPERATING COSTS ($ PER YR)		*Capital costs are 1969
Maint. Material	$ 93,400	figures which are projected
Maint. Labor		to a 1973 base.
Dir. Labor	193,500	
Dir. Materials	89,200	
Overhead	4,700	*Operating Expenses for 6
Utilities	45,200	day operation are projected
Taxes	NS	from the 5 day operation
Insurance	NS	total figure.
Interest	NS	
Disposal of Residue	NS	
Payroll Benefits	NS	
Fuel	NS	
Misc.: Depreciation	7,000	
Truck Operating Expense	35,000	
Administration	20,000	
TOTAL	$ 488,000	$ 586,000
CREDITS ASSUMED ($ PER YR)	$ 353,340	$ 424,000

NOTE: Using the assumptions made in this report, a net cost per metric ton was computed, and it is $3.93 and $3.46 for the 5 day and the 6 day operation respectively.

	DOLLARS/YR 5 days/week	COMMENT 6 days/week
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals		
Nonmagnetic Metals		
Glass		
Ash		
Paper		
Other: Heating value of Refuse*	$ 353,340	$ 424,008
TOTAL ($ PER YR.)	$ 353,340	$ 424,008

*Based on 453 tons/day of refuse as supplementary fuel at $3.31/metric ton ($3.00/ton).

TABLE 3-14 (B)

PROCESS NAME: Horner-Shifrin Supplementary Fuel
DATA SOURCE: Reference 3-32
CAPACITY IN TONS/DAY: 889 metric tons (980 tons) per day (two shifts, one processing unit)

	DOLLARS 231,104 metric tons (254,800 TPY) 5 days/week	COMMENTS 277,324 metric tons (305,760TPY) 6 days/week
CAPITAL COSTS (TOT. $)		
Land	$ 150,000	
Preprocessing Eqmt	411,000	Assumes:
Processing Eqmt	2,019,000	*Financing by means of
Postprocessing Eqmt	Not Specified	general obligation bonds,
Utilities	NS	with a 20 year term, and
Building & Roads	934,000	an annual interest rate
Site Preparation	44,000	of 5%
Engr. & R & D	285,500	
Plant Startup		
Working Capital		
Misc.: Landfill Site		
Construction Contingencies	316,000	
Escalation to 1973 Costs	926,500	
TOTAL	$5,211,000	$5,211,000
OPERATING COSTS ($ PER YR)		
Maint. Material	$ 171,800	*Capital costs are 1969
Maint. Labor)		figures which are projected
Dir. Labor)	387,000	to a 1973 base.
Dir. Materials	136,400	
Overhead	9,300	*Operating expenses for 6
Utilities	90,400	day operation are projected
Taxes	NS	from the 5 day operation
Insurance	NS	total figure.
Interest	NS	
Disposal of Residue	NS	
Payroll Benefits	NS	
Fuel	NS	
Misc.: Depreciation	7,000	
Truck Operating Expense	70,000	
Administration	25,000	
TOTAL	$ 896,900	$1,075,000
CREDITS ASSUMED ($ PER YR)	$ 706,680	$ 848,016

NOTE: Using the assumptions made in this report, a net cost per ton was computed, and it is $2.64 ($2.39) and $2.33 ($2.11) for the 5 day and the 6 day operation respectively.

	DOLLARS/YR 5 days/week	COMMENT 6 days/week
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals		
Nonmagnetic Metals		
Glass		
Ash		
Paper		
Other: Heating value of refuse*	$ 706,680	$ 848,016
TOTAL ($ PER YR)	$ 706,680	$ 848,016

*906 TPD of refuse as supplementary fuel $3.30/metric ton ($3.00/ton).

TABLE 3-14 (c)

PROCESS NAME: Horner-Shifrin Supplementary Fuel
DATA SOURCE: Reference 3-32
CAPACITY IN TONS/DAY: 889 metric tons (980 TPD) (one shift, two processing units)

	DOLLARS 231,104 metric tons (254,800 TPY) 5 days/week	COMMENTS 277,324 metric tons (305,760 TPY) 6 days/week
CAPITAL COSTS (TOT. $)		
Land	$ 200,000	
Preprocessing Eqmt	499,000	
Processing Eqmt	3,419,000	
Postprocessing Eqmt	Not Specified	Assumes:
Utilities	NS	*Financing by means of general obligation bonds, with a 20 year term, and an annual interest rate of 5%
Building & Roads	1,493,000	
Site Preparation	90,000	
Engr. & R & D	474,500	
Plant Startup	NS	
Working Capital	NS	
Misc.: Landfill Site	175,000	
Construction Contingencies	525,000	
Escalation to 1973 costs	1,485,500	
TOTAL	$8,361,000	$8,361,000
OPERATING COSTS ($ PER YR)		
Maint. Material	$ 171,800	*Capital costs are 1969 figures which are projected to a 1973 base.
Maint. Labor) Dir. Labor)	334,300	
Dir. Materials	171,400	
Overhead	9,300	*Operating expenses for 6 day operation are projected from the 5 day operation total figure.
Utilities	90,400	
Taxes	NS	
Insurance	NS	
Interest	NS	
Disposal of Residue	NS	
Payroll Benefits	NS	
Fuel	NS	
Misc.: Depreciation	13,000	
Truck Operating Expense	70,000	
Administration	25,000	
TOTAL	$ 885,200	$1,060,000
CREDITS ASSUMED ($ PER YR)	$ 706,680	$ 848,016

NOTE: Using the assumptions made in this report, a net cost per ton was computed, and it is $1.66 ($3.33) and $3.18 ($2.89) for the 5 day and the 6 day operation respectively.

	DOLLARS/YR. 5 days/week	COMMENT 6 days/week
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals		
Nonmagnetic Metals		
Glass		
Ash		
Paper		
Other: Heating value of refuse*	$ 706,680	$ 848,016
TOTAL ($ PER YR.)	$ 706,680	$ 848,016

*906 TPD of refuse as supplementary fuel $3.30/metric ton ($3.00/ton).

TABLE 3-14 (D)

PROCESS NAME: Horner-Shifrin Supplementary Fuel
DATA SOURCE: Reference 3-32
CAPACITY IN TONS/DAY: 1333 metric tons (1470 TPD) (two shifts, two processing units)

	DOLLARS 346,655 metric tons (382,200 TPY) 5 days/week	COMMENTS 415,986 metric tons (458,640 TPY) 6 days/week
CAPITAL COSTS (TOT. $)		
Land	$ 200,000	
Preprocessing Eqmt	589,000	
Processing Eqmt	3,567,000	Assumes:
Postprocessing Eqmt	Not specified	*Financing by means of general obligation bonds, with a 20 year year term, and an annual interest rate of 5%.
Utilities	NS	
Building & Roads	1,557,000	
Site Preparation	95,000	
Engr. & R & D	491,500	
Plant Startup	NS	
Working Capital	NS	
Misc.: Landfill Site	175,000	
Construction Contingencies	546,500	
Escalation to 1973 Costs	1,559,000	
TOTAL	$8,780,000	$8,780,000
OPERATING COSTS ($ PER YR)		
Maint. Material	$ 250,000	*Capital costs are 1969 figures which are projected to a 1973 base.
Maint. Labor) Dir. Labor)	549,000	
Dir. Materials	200,400	
Overhead	14,000	*Operating expenses for 6 day operation are projected from the 5 day operation total figure.
Utilities	135,600	
Taxes	NS	
Insurance	NS	
Interest	NS	
Disposal of Residue	NS	
Payroll Benefits	NS	
Fuel	NS	
Misc.: Depreciation	13,000	
Truck Operating Expense	105,000	
Administration	30,000	
TOTAL	$1,304,000	$1,565,000
CREDITS ASSUMED ($ PER YR)	$1,060,020	$1,272,024

NOTE: Using the assumptions made in this report, a net cost per ton was computed, and it is $2.73 ($2,48) and $2.39 ($2.17) for the 5 day and the 6 day operation respectively.

	DOLLARS/YR 5 days/week	COMMENT 6 days/week
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals		
Nonmagnetic Metals		
Glass		
Ash		
Paper		
Other: Heating value of supplementary fuel*	$1,060,020	$1,272,024
TOTAL ($ PER YR.)	$1,060,020	$1,272,024

*1359 TPD of refuse as supplementary fuel at $3.30/metric ton ($3.00/ton).

TABLE 3-14 (E)

PROCESS NAME: Horner-Shifrin Supplementary Fuel
DATA SOURCE: Reference 3-32
CAPACITY IN TONS/DAY: 1333 metric tons (1470 TPD) (one shift, three processing units)

	DOLLARS 346,655 metric tons (382,200 TPY) 5 days/week	COMMENTS 415,986 metric tons (458,640 TPY) 6 days/week
CAPITAL COSTS (TOT. $)		
Land	$ 250,000	Assumes: *Financing by means of general obligation bonds, with a 20 year term, and an annual interest rate of 5%.
Preprocessing Eqmt	721,000	
Processing Eqmt	4,926,000	
Postprocessing Eqmt	Not specified	
Utilities	NS	
Building & Roads	2,265,000	
Site Preparation	135,000	
Engr. & R & D	593,500	
Plant Startup	NS	
Working Capital	NS	
Misc.: Landfill Site	200,000	
Construction Contingencies	769,500	
Escalation to 1973 Costs	2,128,000	
TOTAL	$11,988,000	$11,988,000
OPERATING COSTS ($ PER YR)		
Maint. Material	$ 260,200	*Capital costs are 1969 figures which are projected to a 1973 base.
Maint. Labor) Dir. Labor)	445,400	
Dir. Materials	283,100	*Operating expenses for 6 day operation are projected from the 5 day operation total figure.
Overhead	14,000	
Utilities	135,600	
Taxes	NS	
Insurance	NS	
Interest	NS	
Disposal of Residue	NS	
Payroll Benefits	NS	
Fuel	NS	
Misc.: Depreciation	24,000	
Truck Operating Expense	140,000	
Administration	35,000	
TOTAL	$1,337,300	$1,605,000
CREDITS ASSUMED ($ PER YR)	$1,060,020	$1,272,024

NOTE: Using the assumptions made in this report, a net cost per ton was computed and it is $3.57 ($3.24) and $3.41 ($2.82) for the 5 day and the 6 day operation respectively.

	DOLLARS/YR. 5 days/week	COMMENT 6 days/week
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals		
Nonmagnetic Metals		
Glass		
Ash		
Paper		
Other: Heating Value of Refuse*	$1,060,020	$1,272,024
TOTAL ($ PER YR.)	$1,060,020	$1,272,024

*1359 TPD of refuse as supplementary fuel $3.30/metric ton ($3.00/ton).

TABLE 3-15
ECONOMIC DATA-ST. LOUIS SUPPLEMENTAL FUEL SYSTEM
PROCESS COST SHEET

PROCESS NAME: Horner-Shifrin Supplementary Fuel
DATA SOURCE: Reference 3-2
CAPACITY IN TONS/DAY: 907 metric tons (1000 TPD)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land	$ 300,000(1)	*Assumes a municipally owned and operated facility.
Preprocessing Eqmt	2,760,000(2)	
Processing Eqmt	Not Specified	
Postprocessing Eqmt	NS	
Utilities	NS	
Building & Roads	NS	
Site Preparation	(Included above)	
Engr. & R & D	744,000(3)	
Plant Startup	133,000(3)	
Working Capital	200,000(1)	
Misc.:		
Auxiliary & Suppt. Facilities	3,440,000(2)	
TOTAL	$7,577,000	
OPERATING COSTS ($ PER YR)		(1) Not amortized: they are treated as recoverable investment; only interest at the rate of 5% annually is charged to operating cost (under interest).
Maint. Material	Not Specified	
Maint. Labor	NS	
Dir. Labor	NS	
Dir. Materials	NS	
Overhead	NS	
Utilities	NS	
Taxes	--	
Insurance	31,000	(2) Amortized over 20 years at 5% per year.
Interest	25,000(1)	
Disposal of Residue	Not considered	
Payroll Benefits	NS	(3) Amortized over 5 years at 5% per year.
Fuel		
Misc.:		
Administrative & Gen.	62,000	(4) Only global amounts given.
Operating Costs	798,000(4)	
Fixed Costs	116,000(4)	
TOTAL	$1,032,000	
CREDITS ASSUMED ($ PER YR)	$ 920,00	

NOTE: Using the assumptions made in this report, a net cost per ton was computed and it is $2.99 ($2.71). The corresponding net cost per ton for the 227 (250), 454 (500), and 1814 (2000) capacity plants are $6.27 ($5.69), $4.45 ($4.04), and $1.79 ($1.62), respectively.

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals *Ferrous	$ 245,000	
Nonmagnetic metals		
Glass		
Ash		
Paper		
Other: Heating value of refuse**	675,000	
TOTAL ($ PER YR.)	$ 920,000	

*6.8% of 272,000 metric tons (300,000 tons), each $13.23/metric ton ($12/ton)
**2.85 x 10^{15} joules (2.7 x 10^{12} Btu) at $0.237/$10^9$ joules ($0.25/$10^6$ Btu)

TABLE 3-16
ECONOMIC DATA-ST. LOUIS SUPPLEMENTAL FUEL SYSTEM
PROCESS COST SHEET

PROCESS NAME: Horner-Shifrin Supplementary Fuel
DATA SOURCE: Reference 3-21
CAPACITY IN TONS/DAY: 1406 metric tons (1550 TPD)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities		
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	$9,300,000	
OPERATING COSTS ($ PER YR)		
Maint. Material		
Maint. Labor		
Dir. Materials		
Overhead		
Utilities		
Taxes		
Insurance		
Interest		
Disposal of Residue		
Payroll Benefits		
Fuel Refuse preparation	$2,670,340	
Misc.: Combustion process	752,448	
Materials recovery	147,095	
Transfer & storage	594,038	
Disposal of 20% residue	565,750	
TOTAL	$4,729,671	
CREDITS ASSUMED ($ PER YR)	$2,987,160	

NOTE: Using the assumptions made in this report a net cost per ton was computed and it is $5.33 ($4.83).

	DOLLARS	COMMENTS
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals Ferrous*	$ 339,450	
Nonmagnetic Metals		
Glass		
Ash		
Paper		
Other: Heating value of refuse**	2,647,710	
TOTAL ($ PER YR)	$2,987,160	

*$11/metric ton ($10/ton) of metal (metal recovered is 6% of input)
**$0.57/$10^9$ joules ($0.60/$10^6$ Btu)

Net credit given for recovery of metal, \$/ton of metal	\$11/metric ton (\$10/ton)
Recovery rate for metal, % of input	6
Net credit for use of waste as suppl. fuel	$\$0.57/10^9$ joules ($\$0.60/10^6$ Btu)
Fraction of input refuse that is converted to suppl. fuel	Not specified

Comments on Table 3-17

EPA's Second Report to Congress (ref. 3-20) does not specify what interest rate is used nor what useful life is assumed. This source does not specify what type of ownership is assumed.

The following are cost parameters which were used in this report:

Interest rate, %	Not specified
Useful life assumed, years	NS
Land costs, \$/acre	NS
Heating value of refuse	$\$1.10 \times 10^{10}$ joules/metric ton (9.5×10^6 Btu/ton)
Residue disposal costs, \$/ton	NS
Waste residues to be landfilled, % of input refuse	13
Net Credit given for recovery of metal, \$/ton metal	\$18.75/metric ton (\$17/ton)
Recovery rate for metal, % of input	5.88
Net credit for use of waste as supp. fuel, \$/million BTU	
Fraction of input refuse that is converted to suppl. fuel	80

The data for this source is based on 1971 actual costs and estimated 1972 operating and maintenance costs assuming 260 days of operation per year.

Computations for the estimated net cost/ton may be found in the appendix section.

Standardized Gross and Net Cost/Ton for The Horner Shifrin Supplementary Fuel Process

As can be seen from the Process Cost Sheets shown in Tables 3-14 to 3-17, there is significant variability in the costs quoted in various sources for a Horner-Shifrin supplementary fuel processing plant of fixed capacity. It can be noted in other sections of this report that this is also the case for all of the other processes reported herein. Much of the variance found in these cost figures is mainly due to the different assumptions used in the reports; parameters such as heating value of refuse, net credits given for recovered energy and products and interest rate used in the computations. All have a great effect on the final computed value of net cost per ton.

To be able to appreciate the true variability among the cost data given earlier it becomes necessary to standardize, in some fashion, the parameters under which the net cost per ton figures are computed.

Consider as an example, the Horner-Shifrin supplementary fuel process.. It is felt that the following basic parameters should be applied to all data sources.

1. Processing plant is wholly owned by the municipality.
2. Ferrous metal, which is assumed recovered at the rate of 6 percent of input refuse, is sold at a net price of \$33/metric ton (\$30/ton) of metal.
3. Supplementary fuel (70 percent of input refuse) is sold to a utility company at a net price of $\$0.32/10^9$ joules (\$0.34 per million BTU).
4. Supplementary fuel is assumed to have a heating value of 1.05×10^{10} joules/metric ton (9×10^6 BTU/ton).
5. It is assumed that input refuse, as received, has 12 percent moisture, that 70 percent is converted to supplementary fuel and that 6 percent is metal; there is thus 12 percent of the input refuse which is landfilled at an assumed cost of \$3.30/metric ton (\$3/ton) to the municipality.
6. Plant life is assumed to be 20 years.
7. All dollar figures are 1974 estimates.

TABLE 3-17
ST. LOUIS SUPPLEMENTAL FUEL SYSTEM
PROCESS COST SHEET

PROCESS NAME: Horner-Shifrin Supplementary Fuel
DATA SOURCE: Reference 3-20
CAPACITY IN TONS/DAY: 590 metric tons per day (650 TPD)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqm-		
Utilities		
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	$2,394,000	
OPERATING COSTS ($ PER YR)		
Maint. Material		
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead		
Utilities		
Taxes		
Insurance		
Interest		
Disposal of Residue		
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	$ 618,000	
CREDITS ASSUMED ($ PER YR)	$ 169,000	

NOTE: Using the assumptions made in this report a net cost per ton was computed and it is $4.41 ($4.00).

	DOLLARS	COMMENTS
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals	$ 169,000	
Nonmagnetic Metals		
Glass		
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	$ 169,000	

8. Investment is financed at an annual net rate of 8 percent.

Using the above parameters, the gross and the net costs per ton were recomputed for all data sources considered under the Horner-Shifrin supplementary fuel process; the standardized costs are shown in Figures 3-44 and 3-45, and are presented in tabular form in Table 3-18.

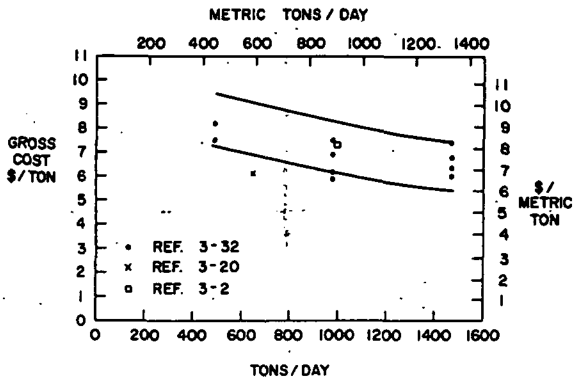


FIGURE 3-44
VARIATION IN GROSS COST PER TON
FOR ST. LOUIS SUPPLEMENTAL FUEL PROJECT

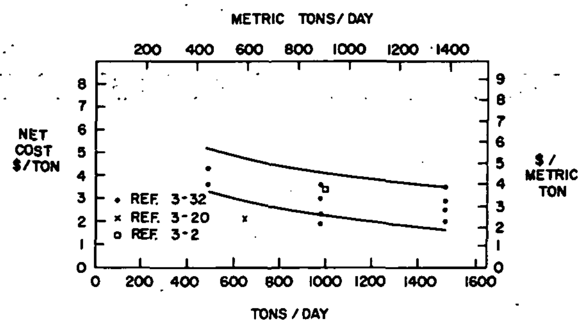


FIGURE 3-45
VARIATION IN NET COST PER TON
FOR ST. LOUIS SUPPLEMENTAL FUEL PROJECT

Figures 3-44 and 3-45 give some idea as to the general trends and ranges that can be observed when plotting both the "standardized gross costs per ton, and the net costs per ton. A set of estimated lower and upper bounds on the costs per ton gives a range of costs in which the true estimated values are expected to fall.

Sensitivity of Net Cost/Ton to Credits Assumed

One very important question that should be investigated in the sensitivity of the net cost per ton to the values of the credits assumed. Even though the Figures presented earlier, Figures 3-44 and 3-45, do show wide expected ranges in both the gross and net costs per ton, they do not show the sensitivity of the net cost per ton to the values of the credits received for both the recovered metals and the supplementary fuel.

Assuming a gross cost of $8.27/metric ton ($7.50/ton) for a 907 metric ton (1000 ton) Horner-Shifrin supplementary fuel processing plant operating 260 days per year, a graph may be prepared which depicts the sensitivity of the net cost per ton of the process to the values of the credits given for both metals and supplementary fuel. Figure 3-46 has been prepared under the following additional assumptions:

1. Heating value of prepared refuse is 9.3×10^9 joules/metric ton (8×10^6 Btu/ton).
2. The effective ferrous metal recovery rate is 6 percent of the input refuse.
3. Supplementary fuel is 70 percent of the input refuse.

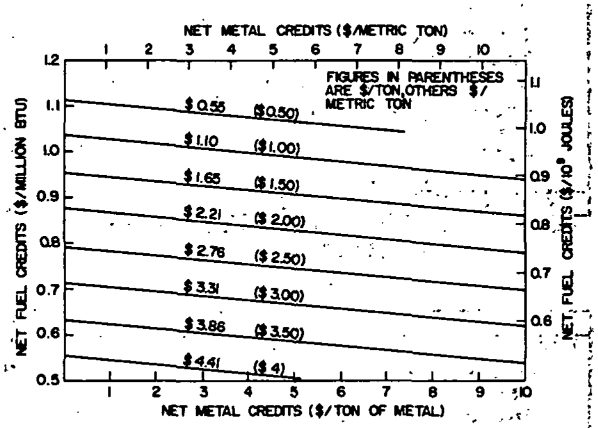


FIGURE 3-46
SENSITIVITY OF NET COST/TON
(FOR 1000 TON/DAY SUPPLEMENTARY FUEL PROCESS)
TO FUEL & METAL CREDITS

Figure 3-46 shows how, for different combinations of fuel and metal credits, the net cost per ton of a Horner-Shifrin 907 metric ton (1000 ton) per day plant varies. The parallel lines correspond to different assumed credit - combinations, all of which yield the same net cost per ton. As can be seen, the Horner-Shifrin supplementary fuel process could easily compete with landfill in areas of the country where:

1. Landfill costs are high,
2. There are high attainable fuel and metal credits or, where a combination of both is present.

If a city has some idea as to what possible credits it can obtain from the

TABLE 3-18
"STANDARDIZED" COSTS PER TON FOR THE
HORNER SHIFRIN SUPPLEMENTARY FUEL PROCESS

Source	Metric Tons	(TPD)	Gross Cost: $ per metric ton	Gross Cost: $ per ton	Net Cost: $ per metric ton	Net Cost: $ per ton
Horner-Shifrin report to the EPA (EPA-SW-36D-73) (ref. 3-32)	444	(490)	$9.04	($8.20)	$4.74	($4.30)
Horner-Shifrin report to the EPA (EPA-SW-36D-73) (ref. 3-32)	444	(490)	8.27	(7.50)	3.97	(3.60)
EPA's second report to Congress (ref. 3-20)	560	(650)	6.73	(6.10)	2.32	(2.10)
Horner-Shifrin report to the EPA (EPA-SW-36D-73) (ref. 3-32)	889	(980)	6.84	(6.20)	2.54	(2.30)
Horner-Shifrin report to the EPA (EPA-SW-36D-73) (ref. 3-32)	889	(980)	6.50	(5.90)	2.09	(1.90)
Horner-Shifrin report to the EPA (EPA-SW-36D-73) (ref. 3-32)	889	(980)	8.27	(7.50)	3.97	(3.60)
Horner-Shifrin report to the EPA (EPA-SW-36D-73) (ref. 3-32)	889	(980)	7.61	(6.90)	3.31	(3.00)
Midwest Research Institute: Resource Recovery: State of Technology (ref. 3-2)	907	(1000)	8.05	(7.30)	3.75	(3.40)
Horner-Shifrin Report to the EPA (EPA-SW-36D-73) (ref. 3-32)	1333	(1470)	7.06	(6.40)	2.76	(2.50)
Horner Shifrin Report to the EPA (EPA-SW-36D-73) (ref.3-32)	1333	(1470)	6.62	(6.00)	2.21	(2.00)
Horner Shifrin Report to the EPA (EPA-SW-36D-73) (ref. 3-32)	1333	(1470)	8.16	(7.40)	3.86	(3.50)
Horner Shifrin Report to the EPA (EPA-SW-36D-73) (ref. 3-32)	1333	(1470	7.50	(6.80)	3.20	(2.90)

selling of recovered ferrous metal scrap and from the sale of the prepared suplementary fuel, figure 3-46 could then be used to estimate the city's net cost per ton. Comparing this net cost with their current landfill costs, the city could have a very good idea as to the possible economic advantages (or disadvantages) of changing from landfill to a Horner-Shifrin supplementary fuel process.

Assume, for example, the case of a city in which current landfill costs are $4.41/metric ton ($4/ton). Further assume that recovered ferrous metal can be sold for $18.74/metric ton ($17/ton) but that the cost of handling and transporting the recovered metal to the buyer are $17.09/metric ton ($15.50 per ton): the net metal credit is $1.65/metric ton ($1.50 per ton). If the city can sell the prepared refuse to a utility company for at least a net $0.51/10^9 joules ($0.54 per million Btu) (after considering the preparation, handling and transportation costs of delivering the prepared refuse to the utility), it would be more economical for the city to change to a supplementary fuel conversion process of the Horner-Shifrin type rather than continue to landfill.

Summarizing, it can be said that the net cost per ton in a supplementary fuel process is sensitive to both the fuel credits and the metal credits, and it is more sensitive to the fuel credits. The recent increases in the prices of coal and other fuels, coupled with the increased costs of landfilling in most urban centers will have a very positive effect on the competitiveness of the supplemental fuel processes similar to Horner-Shifrin. This should be of great interest to the more densely populated areas such as the Metropolitan Statistical areas (SMSA's) which have utility companies burning fuel that can be combined with prepared mixed municipal refuse. As to how soon this process becomes economically feasible in these large urban centers, this will depend on:

1. Whatever limitations are identified in the plants undergoing tests (for example; corrosion and pollution problems in the St. Louis plant),

2. Whatever markets are found primarily for supplementary fuel, and secondarily for the ferrous and non-ferrous metals.

3. The costs of other conversion process options, including landfill.

Cities interested in studying the possibilities of the Horner-Shifrin supplementary fuel process should obtain information from the EPA on the experiments that have been, and are being conducted in St. Louis. A forthcoming report by Gordian Associates Incorporated, to be published by the EPA, and titled Where the Boilers Are: A Survey of Electric Utility Boilers with Potential Capacity for Burning Solid Waste as a Fuel should also provide valuable information to cities desiring to look closer into this energy conversion approach to the problem of solid waste.

3.3.3.4 SOLID FUEL INCINERATION - Eco-Fuel™

3.3.3.4.1 Technical Description

The flow diagrams for the production of both Eco-Fuel™ I and Eco-Fuel™ II were discussed previously in section 3.2.4.2. This pre-processing includes shredding, separation, and drying, leaving a combustible fraction with a relatively high heating value (ref. 3-17).

The first generation fuel made by Combustion Equipment Associates (CEA), Eco-Fuel™ I, has physical and general properties as noted in Table 3-19. The moisture content averaged 10 percent, and 78.5 percent of the solid fuel was combustible. The sulphur content varied between 0.1 and 0.2 percent, which means that the off gases would be low in SO_x.

The fly ash resulting from the burning of refuse is expected to be equivalent to that of coal. Electrostatic precipitators or fabric filters could therefore be used to collect these particulates. Double vortex (DV) burners are recommended for the firing of the Eco-Fuel™ I. There appears to be good mixing of the solid fuel and combustion air in a commercial boiler; thus the concentration of CO is low, less than 8 parts per million. The NO_x emissions from the burning of Eco-Fuel™ are expected to be less than that of burning coal (ref. 3-17)

One of the disadvantages of Eco-Fuel™ I was its low bulk density. CEA subsequently developed Eco-Fuel™ II, which has a higher bulk density and requires no special handling. The second generation solid fuel is chemically treated and undergoes a superior separation system. The organic fraction can be processed into a very fine powder. The overall characteristics of Eco-Fuel™ II are expected to be superior to Eco-Fuel™ I.

TABLE 3-19
PROPERTIES OF ECO-FUEL™ I (REF. 3-17)

Estimated Composition

Component	Percent by weight (as fired)
Paper	45.0
Wood	9.3
Leather	0.7
Rubber	1.2
Plastics	2.7
Textiles	2.7
Food Wastes	10.3
Yard Wastes	13.1
Inerts	5.0
Moisture	10.0
	100.0

Estimated Chemical Analysis

Component	Percent by weight (as fired)
Carbon	39.6
Hydrogen	5.3
Oxygen	32.3
Nitrogen	0.9
Ash	11.5
Sulphur	0.1 - 0.2
Chloride	0.1 - 0.2
Water	10.0
	100.0

Generalized Properties

Component	Percent by Weight (as fired)
Combustibles	78.5
Ash	11.5
Moisture	10.0
	100.0

Higher Heating Value	$1.6 \times 10^8 \frac{\text{joule}}{\text{kg}}$ (6900 Btu/lb)
Particle size	1.25 cm or less (½" or less)
Bulk density	112-160 kg/m^3 (7-10 lb/ft^3)
Storage life	Indefinite
Approximate Ash Fusion Temp.	1200-1425°C (2200-2600°F)
Pounds air/pound fuel	6.0

A summary of the properties of Eco-Fuel™ II is given in Table 3-20. The heating value of the refuse fuel has been increased 10 to 20 percent over that of Eco-Fuel™ I. In fine powder form the fuel is easily transported, and should provide good burning characteristics when burned in the DV furnance.

CEA has a contract with the State of Connecticut to provide a resource recovery and Eco-Fuel™ II preparation plant, as well as facilities for the firing of refuse to produce steam. The facilities are expected to be in operation in 1976. In the meantime, additional research will be conducted by CEA at their Brockton, Massachusetts, plant to determine optimum particle size for the solid fuel refuse burning.

TABLE 3-20
PROPERTIES OF ECO-FUEL™ II

Particle size: 0.6 cm to 100 mesh (-1/4 inch to -100 mesh)
Higher Heating Value: 1.74-1.86 X $10^8 \frac{\text{joule}}{\text{kg}}$ (7500-8000 Btu/lb)
Moisture Content: less than 2% by weight
Storage life: indefinite
Bulk density: 480 kg/m^3 (30 lb/ft^3)
Handling Properties: free flowing powder

3.3.3.4.2 Economic Data for Eco-Fuel™ II

The economic data for Eco-Fuel™ II was received by telephone from Ken Rogers of Combustion Equipment Associates, Inc., of New York. He stressed the importance of the concept that costs and credits depend on local conditions and local market prices. He gave cost and credit ranges which are generally expected in the Connecticut project (ref. 3-44). The figures presented in the process cost sheet and resource recovery data are estimated from these ranges.

These cost estimates might be somewhat high because they are based on a plant capacity of 1814 metric ton/day (2000 ton/day), while the normal operating capacity is a nominal 907 metric ton/day (1000 ton/day).

3.3.4 Summary of Incineration Systems

Several possible applications of incineration with energy recovery have been examined to determine performance and cost. These have included:

1. Direct incineration of refuse with steam generation.
2. Direct incineration with electrical power generation.
3. Supplemental fuel incineration with steam generation.
4. Direct incineration of refuse as a prepared solid fuel for steam generation.

The profit potential of operating a solid waste system with energy recovery depends on a number of variables including:

plant capital cost
plant operation and maintenance cost
present solid waste disposal cost
local price of energy
local market for energy
energy conversion efficiency.

Local credits for energy and resource will be one of the prime factors in the economics of a system recovering energy from MMR.

One point that has not been strongly emphasized is the quality of personnel required to operate a large scale energy recovery system. The incinerator plants are complex and require the services of trained operators and skilled workers. A well-designed system staffed with inadequately trained personnel will not be successful.

3.4 PYROLYSIS PROCESSES

3.4.1 Introduction

Pyrolysis is defined as thermal decomposition without complete combustion. If a storable fuel is desired, either gas, liquid, or solid, pyrolysis offers a viable option with a minimum amount of landfill and pollution control problems. The process technology however, has not been widely demonstrated on a commercial scale and thus there is considerable confusion regarding vendor technical and economic claims.

In this section, general considerations will be presented, (reaction and reactor types, process variables, heating methods, feed conditions and product distribution) followed by a brief description of reported pyrolysis processes. Selected processes will then be analyzed in greater detail. A summary and suggestions for further research will conclude the section.

3.4.2 General Considerations

PROCESS COST SHEET

PROCESS NAME: Eco Fuel^{TM} II
DATA SOURCE: Ken Rogers of CEA Inc., New York (telephone conversation on 8/6/74)
CAPACITY IN TONS/DAY: 1814 metric (2000)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities		
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	20,000,000	
OPERATING COSTS ($ PER YR)		907 Metric ton/day operation (1000 ton/day operation)
Maint. Material		
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead		
Utilities		This cost ranges from 2,000,000 to 2,500,000
Taxes		
Insurance		
Interest		
Disposal of Residue		
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	2,250,000	

		COMMENT
		907 Metric ton/day operation (1000 ton/day operation)
Fuel:		
Liquid		
Gas		
Solid	1,875,000	This credit ranges from 1,500,000 to 2,250,000 as the Fuel credit varies from $6 to $9 per ton
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals		
Nonmagnetic Metals		
Glass	625,000	This varies from $500,000 to $750,000
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	2,500,000*	

*On a $/ton basis this represents a net cost of $11/metric ton ($10/ton) for refuse disposal. This net price is highly dependent on the value of energy credits and recovered resources and is probably a conservative number. The net disposal cost in Connecticut could be less than $5.51/metric ton ($5/ton) under optimum operating conditions.

3.4.2.1 CHEMICAL REACTIONS

Pyrolysis is a complex process of simultaneous and consecutive chemical reactions. While a complete description of the specific reaction types occurring has not been determined, it is generally believed that reactions such as cross linking, isomerization, de-oxygenation, de-nitrogenation, etc. do occur. The reactive portion of the solid waste is composed primarily of cellulosic material. An empirical formula has been proposed for MMR by Burton and Bailie (ref. 3-45): $C_{30}H_{48}O_{19}N_{0.5}S_{0.05}$. The decomposition of the cellulosic material starts to occur at about 180°C (360°F), producing a mixture of solids, liquid and gas, the proportions and composition depending on reactor conditions and environment (ref. 3-46).

3.4.2.2 REACTOR TYPES

Several basic reactor types have been used for pyrolysis reactions. The most common can be classified as follows: (1) shaft, (2) rotary kiln, and (3) fluidized bed.

Shaft reactors (horizontal and vertical) are conceptually the simplest and lowest in capital cost. In the vertical type, the feed material is fed into the top of the reactor and settles into the reactor under its own weight. Generated pyrolysis gases pass upward thru the shaft and are removed from the top. Typical feed mechanisms include screw conveyors, rotary devices and rams. A residue discharge device and gas takeoff manifold must be provided. The horizontal shaft type incorporates a feed conveyor system (e.g., mechanical, molten bed) thru the reactor housing. Refuse is thus continuously pyrolyzed from the conveyor system. Feed and discharge problems are minimized but reliability of conveyors at elevated temperatures can be a problem. Both types of vessels are constructed of metal capable of withstanding high temperatures 260-1650°C (500-3000°F) or are lined with a refractory material.

The rotary kiln is a cylinder rotated upon suitable bearings and usually slightly inclined to the horizontal. Typical length/diameter ratios are in the range of 4 to 10. Feed material is charged into one end of the kiln and progresses thru the kiln by means of rotation and slope of the cylinder to the opposite end where it is discharged. Feed and discharge mechanisms must be provided. The metal cylinder is normally lined with a refractory brick. The rotary kiln has mixing advantages over the shaft type reactor but the sealing of the rotating cylinder from the stationary feed and discharge ports can be a problem.

The fluidized bed reactor consists of a bed of solid particles (e.g., sand) suspended by an upward flowing gas stream. For pyrolysis applications, the solid particles are heated (same vessel or external vessel with circulation) and serve as the heat source for the pyrolysis reactions. A chemical reaction involving the solid particles may occur (e.g. dolomite $MgO.CaCO_3 + CO_2$ [exothermic]). The major advantage over other reactor types is improved heat transfer and temperature control. The primary drawbacks include erosion and carry over problems associated with the solid particles, gas velocity control and solids transfer and separation problems.

3.4.2.3 PROCESS VARIABLES

The key reactor control variable is the temperature of pyrolysis. The yield and composition of products can be significantly altered by manipulation of the reactor temperature profile. Thus at high temperatures 16000°C (3000°F), the reactor products consist primarily of gas and slag phases. The gas consists of low molecular weight hydrocarbons and other gases such as H_2, CO, CO_2, etc. The slag consists of a fused mass of solid residue. As the temperature is lowered, the gas phase becomes richer in higher molecular weight hydrocarbons and a liquid phase may also be present. The solid residue phase also becomes more heterogenous at lower temperatures.

3.4.2.4 HEATING METHODS

Pyrolysis reactions are generally considered endothermic and require a heat source. Two distinct heating methods are used, direct and indirect. In this report, a "direct" method refers to a procedure whereby heat is supplied to the reaction mixture by partial combustion of refuse and/or supplementary fuel within the pyrolysis reactor. Oxygen must be supplied and the reactor product gas contains a significant amount of CO_2 and H_2O, with resulting reduced heating value.

If air is used as the oxygen source, the environmental problems of NO_x formation must be considered, as well as the further dilution of the pyrolysis gas by large amounts of N_2. "Indirect" heating methods refer to methods in which the primary heating zone is separated from the pyrolysis vessel. This separation can be achieved by a heat conduction barrier (wall) or by transfer of a separate medium between the combustion and pyrolysis vessels (e.g., sand, molten bed). Wall heat transfer methods are generally unacceptable in solid waste applications due to large resistances such as refractory linings, slag coatings, and corrosion problems. The use of a separate medium is desirable from a heat transfer viewpoint but can present major problems with regard to solids transfer and separation. Indirect methods are generally less efficient than direct methods but avoid the problems of excessive CO_2 and H_2O formation (reduced heating value) and high NO_x and N_2 content.

The general relationships of reactor type and heating method to operation simplicity and high heating rates are shown in Table 3-22. Thus, for example, a rotary kiln system with indirect heating via a circulating solid medium would be expected to have excellent heat transfer characteristics but severe solids handling and separation operational problems.

3.4.2.5 FEED CONDITIONS

Pyrolysis reactors have been designed to handle a variety of refuse feed conditions. Thus some systems will accept raw municipal refuse while others may require some pre-conversion, such as size reduction or separation of different types of inorganic material. Conceptually, a system that is designed to handle a raw feed can also accept a preprocessed feed. The preprocessing decisions are sometimes dictated by inorganic product-utilization considerations but also have a direct effect on required reactor equipment such as feed and discharge devices etc. In general, a dried, finely shredded feed with solid inorganics removed is most desirable from a reaction viewpoint.

3.4.2.6 PRODUCT DISTRIBUTION

The pyrolysis reactor output can consist of liquid, solid and gas phases. The composition and amounts of each phase will be dictated primarily by:

1. the amount of preprocessing (separation and sizing),
2. reactor temperature and residence time,
3. heating method (direct or indirect).

The virtues of different product distributions is a utilization consideration that is discussed in Chapter 4 of this report. A general indication of the effect of residence time, temperature and particle size on product distribution is shown in Figure 3-47. For example, for a given reactor temperature and particle size a decrease in particle size will tend to increase gas production and decrease solid and liquid fuel production. The relationships are very complex and interrelated and are not well understood.

3.4.3 DESCRIPTION OF PROCESSES

Table 3-23 lists twenty-four pyrolysis projects in progress or completed. The

TABLE 3-22
REACTOR TYPE CHARACTERISTICS

	DIRECT HEATING		INDIRECT HEATING			
			WALL TRANSFER		CIRC. MEDIUM	
	OPERATIONAL SIMPLICITY	HIGH HEATING RATE	OPERATIONAL SIMPLICITY	HIGH HEATING RATE	OPERATIONAL SIMPLICITY	HIGH HEATING RATE
Vert. Shaft	+		+	-	-	+
Horizon. Shaft	NONE	NONE	-	-	-	+
Rotary Kiln	+		+	-	-	+
Fluid. Bed	-	+	NONE	NONE	-	+

NOTE: 1. A plus (+) entry indicates a virtue while a minus (-) entry indicates a detriment.
2. A NONE entry indicates that no process development has been reported in that category.
3. No entry implies neither a virtue nor a detriment.

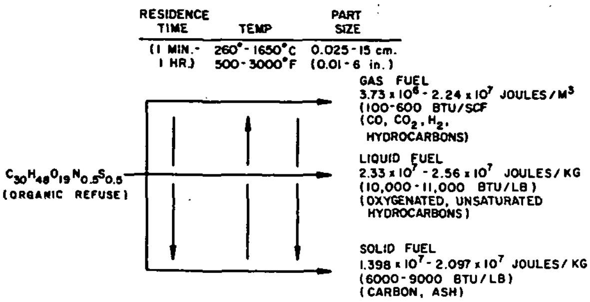


FIGURE 3-47
EFFECTS OF TIME, TEMPERATURE, AND PARTICLE SIZE ON PYROLYSIS PRODUCT DISTRIBUTIONS

major headings are:

1. heating method,
2. product distribution,
3. feed conditions,
4. reactor temperature,
5. status,
6. references.

Lack of entry within a major heading implies that information is not available. All of the commercial status processes listed are in the design, construction or startup phase.

3.4.3.1 VERTICAL SHAFT REACTORS

3.4.3.1.1

Garrett. (ref. 3-18, 3-21, 3-22, 3-28, 3-47, 3-50, 3-51) The Garrett Research and Development Company (central research organization for the Occidental

TABLE 3-23A
PYROLYSIS REACTOR CLASSIFICATIONS
(METRIC UNITS)

PROCESS	HEATING METHOD		PRODUCT DISTRIBUTION			FEED CONDITIONS			REACTOR TEMP °C	STATUS			REFERENCES
	DIR.	INDIR.	SOLID Joules/kgx10-7	LIQUID Joules/kgx10-7	GAS Joules/m^3	RAW	SIZE RED.	SEPARATION		RES.	Metric Pilot Plant	Tons/Day Comm	
VERTICAL SHAFT													
Garrett		X	2.20	2.44	2.04		X	X	482		3.6	180	3-18,-21,-22,-28 -47,-50,-51
Battelle	X				.64		X		982		1.8		3-22,-28,-47,-54 -55
Ga. Tech.	X		2.32	3.02	.74		X		399		23		3-53
URDC	X				.56	X			1427		109		3-26,-47,-48
Torrax	X				.56	X			1650		68		3-26,-28,-47,-48 -52
Union Carbide	X				1.113	X			1650		4.6	180	3-28,-47,-48,-49
HORIZONTAL SHAFT													
Kemp		X	X	X	X		X		593		4.6		3-47
Barber-Colman		X			1.86		X	X	649		.91		3-56
ROTARY KILN													
Monsanto	X		0.57		.48		X		982		32	907	3-21,-22,-28,-47 -60,-61,-62.
Devco	X		X		X		X	X	538		109	1360	Priv. Comm.
Rust Eng		X			1.68				677			236	3-57,-58,-59
Pan Am Res.		X					X		1093	X			3-8,-63,-64
FLUID. BED													
W. Virginia		X			1.68		X	X	760	X			3-65,-66,-67,-68
A.D. Little		X			X		X	X		X			3-70
Coors	X				.56		X	X	760		.91		3-69
OTHER													
Battelle		X							982	X			3-71
Hercules			X							X			3-28,-72
Bur. Mines		X			1.86		X	X	982	X			3-22,-28,-73,-74 -75
NYU		X							927	X			3-76,-77
USC		X								X			Priv. Comm.
Anti. Poll. Syst										X			3-78
Univ. Calif.		X					X			X			3-79
Wallace-Atkins		X	.70	3.71	1.86				871	X			3-80
Res. Sci.		X					X		982		1.8		3-47

TABLE 3-23B
PYROLYSIS REACTOR CLASSIFICATIONS (ENGLISH UNITS)

	HEATING METHOD		PRODUCT DISTRIBUTION			FEED CONDITIONS			REACTOR TEMP	STATUS			REFERENCES
	DIR.	INDIR.	SOLID (BTU/lb)	LIQUID (BTU/lb)	GAS (BTU/ft3)	RAW	SIZE RED.	SEPARATION	°C	RES.	PILOT PLT (TPD)	COMM (TPD)	
VERTICAL SHAFT													
Garrett		X	9,700	10,500	550		X	X	900		4	200	3-18,-21,-22,-28,-47,-50,-51
Battelle	X	X			170		X		1800		2		3-22,-28,-47,-54,-55
Ga. Tech.	X		10,000	13,000	200		X		750		25		3-53
URDC	X				150	X			2600		120		3-26,-47,-48
Torrax	X				150	X			3000		75		3-26,-28,-47,-48,-52
Union Carbide	X				300	X			3000		5	200	3-28,-47,-48,-49
HORIZONTAL SHAFT													
Kemp		X	X	X	X		X		1100		5		3-47
Barber-Colman		X			500		X	X	1200		1		3-56
ROTARY KILN													
Monsanto	X		2,500		130		X		1800		35	1000	3-21,-22,-28,-47,-60,-61,-62
Devco	X		X		X		X	X	1000		120	1500	Priv. Comm.
Rust Eng		X			450				1250			260	3-57,-58,-59
Pan Am Res.		X					X		200	X			3-8,-63,-64
FLUID. BED													
W. Virginia		X			450		X	X	1400	X			3-65,-66,-67,-68
A. D. Little		X			X		X	X		X			3-70
Coors	X				150		X	X	1400		1		3-69
OTHER													
Battelle		X							1800	X			3-71
Hercules			X							X			3-28,-72
Bur. Mines		X			500		X	X	1800	X			3-22,-28,-73,-74,-75
NYU		X							1700	X			3-76,-77
USC		X								X			Priv. Comm.
Anti Poll. Syst.										X			3-78
Univ. Calif.		X					X			X			3-79
Wallace-Atkins		X	3,000	16,000	500				1600	X			3-80
Res. Sci.		X					X		1800		2		3-47

Petroleum Corporation) has modified a coal conversion process to convert municipal refuse to synthetic fuel oil (Figure 3-48). A 1180 metric ton/day (200 ton/day) demonstration plant is being built for San Diego County, California. The process involves extensive preparation, consisting of the following steps:

1. primary shredding of the raw refuse to approximately 5 centimeters (2 in.),
2. air classification to remove most of the inorganics,
3. drying to about 3 percent moisture,
4. screening of the dry material to further reduce the inorganic content (less that 4 percent by weight),

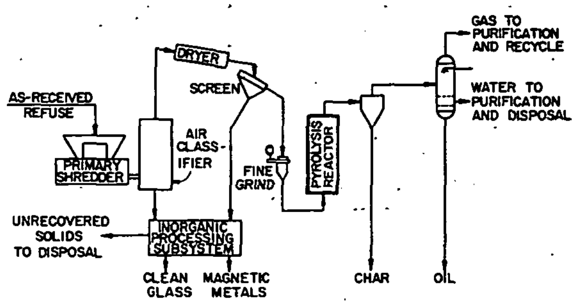


FIGURE 3-48
SCHEMATIC OF GARRETT PYROLYSIS PROCESS

5. recovery of magnetic metals and glass, and
6. secondary shredding of the organics to about 2 mesh.

The organic material is then fed to a vertical shaft pyrolysis reactor at a reactor temperature of about 480°C (900°F) yielding products consisting of char, oil, gas and water phases. An indirect heating method is used. Under optimum liquefacation conditions, oil yields of about 40 percent by weight are obtianed. The gas and part of the char is used on site for process heat. A more detailed analysis of this process will be presented in section 3.4.4.3.

3.4.3.1.2

Battelle - Northwest (Vertical Shaft). (Ref. 3-22, 3-28, 3-47, 3-54, 3-55) Battelle has conducted research on two different systems for converting municipal refuse to marketable products: (1) vertical shaft with direct heat, and (2) molten salt vertical reactor.

The vertical shaft process reactor is illustrated in Figure 3-49. The reactor

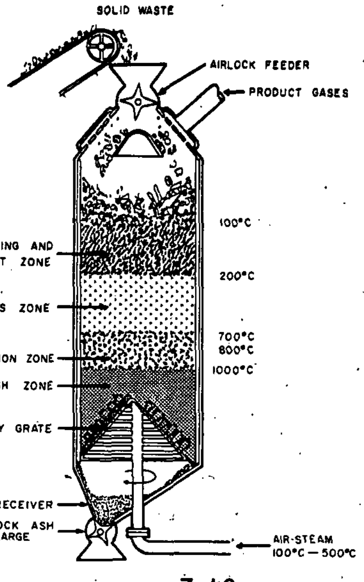


FIGURE 3-49
BATTELLE VERTICAL SHAFT

dimensions are 3.66 meters (12 feet) in length and 0.91 meters (3 feet) in diameter. A refractory lining is used. Solid waste is transferred into the top of the reactor through an air lock device and passes downward through the reactor while an air-steam mixture and product gases pass up through the reactor. The solid waste passes through zones of increasing temperature: drying, pyrolysis, and char gasification. Ash is discharged from the reactor via an airlock. Experiments have been conducted with shredded, unsegregated refuse at a feed rate of approximately 80 kilograms/hour (180 pounds/hour) and pyrolysis temperatures of 700-1000°C (1300-1800°F). A 136 metric ton/day (150 ton/day) plant for the city of Kennewick, Washington has been proposed. Figure 3-50 is a schematic of the proposed Battelle process pyrolysis plant.

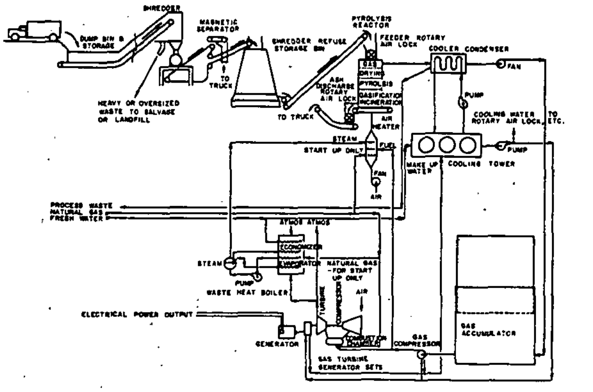


FIGURE 3-50
PROPOSED BATTELLE PROCESS
PYROLYSIS PLANT SCHEMATIC

3.4.3.1.3 Georgia Institute of Technology (Ref. 3-53)

A low temperature vertical shaft pyrolysis system has been developed by the Engineering Experiment Station of Georgia Institute of Technology (see figure 3-51).

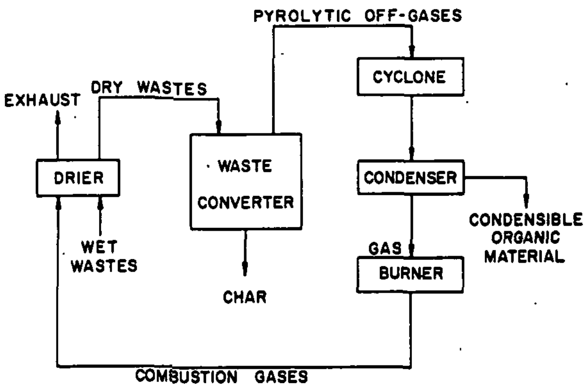


FIGURE 3-51
FLOW DIAGRAM OF
GEORGIA TECH PYROLYSIS SYSTEM

Most of the development work has been done using agriculture or wood wastes, but some testing has also been done with municipal refuse. Actually only the heavy fraction of municipal refuse was used in the tests, which may present more operating difficulty than typical MMR. The process has been operated with partial oxidation with air (without preheating) in the reaction chamber, and with the reactor temperature limited to 400°to 500°C (750° to 930°F). Use of such low temperatures reduces or removes the requirements for insulation of the reactor, and reduces mechanical and materials design problems. Also, the low temperatures used allow the possibility of pos-reactor recovery of most metals and glass, since they will not be melted in the reactor and metal oxidation will be minimized. The low temperature pyrolysis favors the production of large amounts of char and small amounts of gas. The gas (low heating value due to partial oxidation with air) has been used for drying the feed material and powering an internal combustion engine for operation of mechanical equipment.

The char produced has a high heating value and low ash production when the feed material contains little inert material, as in some agricultural and wood wastes. Experiments with mixing the liquid fuel products and the char seem to indicate that this procedure minimizes fuel handling problems and produces a fuel comparable to very low sulphur bituminous coal. Use of MMR as a feed material will definitely reduce the usefulness of the char as a solid fuel due to the quantities of inert materials included, even after screening to remove larger pieces of metal and glass. The char could be used to produce activated charcoal, or could be used to produce a fuel gas by the water-gas reaction or other means for gasifying coal. The low sulfur content would remain as an advantage.

3.4.3.1.4 URDC (Ref. 3-26, 3-47, 3-48.)

The system developed by the Urban Research and Development Corporation (URDC) uses combustion with preheated air of the char from pyrolysis to produce heat for the pyrolysis of MMR (Figure 3-52).

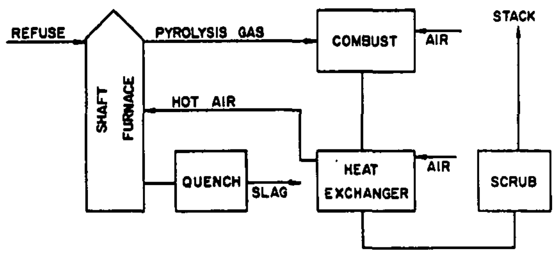


FIGURE 3-52
FLOW DIAGRAM OF URDC PYROLYSIS PROCESS

As raw MMR falls through the vertical shaft it is dried. The organic portion is pyrolyzed, with the char and inorganics falling to the combustion zone at the bottom. The high temperature 1100° -1400°C (2000°-2600° F) in the combustion zone converts inorganics to an inert slag. The low heating value pyrolysis gas 3.7 to 6.0 x 10^6 joules/meter^3 (100 to 160 Btu/ft^3) is burned to preheat the combustion air. Limited data is available from operation of a 22 metric ton/day (24 ton/day) pilot plant (located in Roncari Industries, Inc. quarries) which began operation in 1969, and even less data is available from the 110 metric ton/day (120 ton/day) pilot plant started up in 1973.

It should be noted that the presence of large amounts of nitrogen (from the combustion air) in the pyrolysis gas virtually eliminates the possibility of upgrading any excess gas to pipeline quality by water shift and methanation. Excess gas could, however, be used in specially designed furnaces.

3.4.3.1.5 Torrax (Ref. 3-26, 3-28, 3-47, 3-48, 3-52)

Torrax Systems, Inc., has operated (since 1969) a 68 metric ton/day (75 ton/day) slagging-temperature pilot plant (an EPA demonstration project) in Erie County, N. Y. The process is quite similar to the URDC system. The major diference in operation of the two systems is that Torrax, in the pilot plant operation, burns natural gas to preheat the air, then recovers energy by burning the pyrolysis gas to produce usable steam. Operating experience has included generation of 10,500 to 11,500 kilogram/hour (23,000 to 25,000 pound/hour) of steam while consuming MMR at a rate of 1.8 metric ton/hour (2 ton/hour). Having completed the EPA demonstration project, Torrax, in commercial installations, plans to offer options of burning about 15 percent of the pyrolysis gas for burning in a nearby utility system boiler. Torrax asserts that the net energy recovery after deducting that used in preheating air is as high as 8.7 to 9.3 x 10^9 joules/metric ton (7.5 to 8 x 10^6 Btu/ton) of MMR, representing approximately 80 percent of the energy contained in the raw MMR. This energy data was obtained from Mr. John Stola, Operations Manager, Torrax Systems, Inc., North Tonauanda, N.Y. July, 1974.

3.4.3.1.6 Union Carbide (Ref. 3-28, 3-47, 3-48, 3-49).

The Union Carbide Corporation has developed a slagging temperature pyrolysis system, called the Purox System, which utilizes nearly pure oxygen for the combustion of the pyrolysis char (see figure 3-53). The vertical shaft reactor used is similar in operation to the systems using preheated air, but preheating is not required when pure oxygen is used. The major advantage of using pure oxygen is the fact that the pyrolysis gas is virtually free of nitrogen. The heating value of the pyrolysis is still only about 11 x 10^6 joules/meter^3 (300 Btu/ft^3), compared to about 37 x 10^6 joules/m^3 (1000 Btu/ft^3) for natural gas. The primary combustible components of the pyrolysis are hydrogen and carbon monoxide. Water shift reaction, carbon dioxide removal, and methanation could be used, if desired, to convert this gas to natural gas quality methane. On-site production of the oxygen for the Purox process is estimated to require approximately one-third of the energy available in the pyrolysis gas. This could be accomplished by on-site generation of electricity or by purchase of electricity if all the pyrolysis gas could be sold. A more detailed analysis of this process will be presented later in section 3.4.4.1.

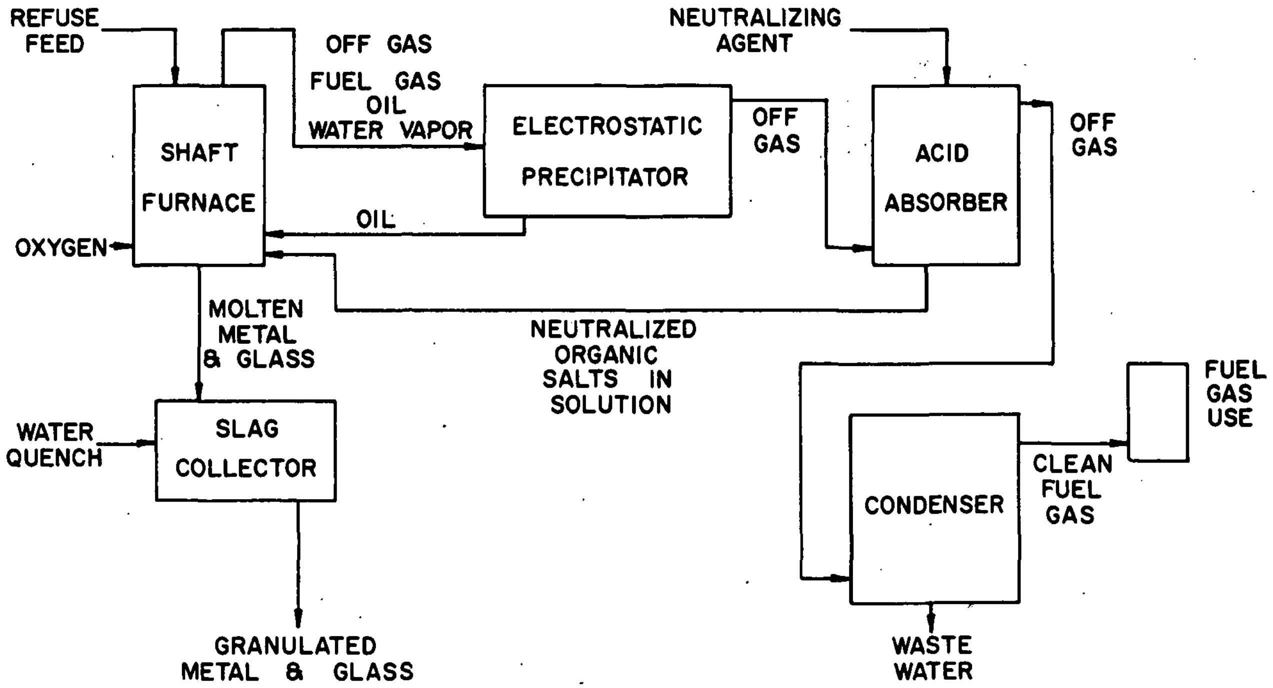


FIGURE 3-53
FLOW DIAGRAM OF UNION CARBIDE PROCESS

3.4.3.2 HORIZONTAL SHAFT

3.4.3.2.1 Kemp Waste Converter (Ref. 3-47)

A conveyor belt is used to carry the feed material through the reactor developed by the Kemp Corporation. Indirect heating is used to pyrolyze the organic material and produce solid, liquid and gaseous fuels. For shredded MMR the pyrolysis temperature would be in the range 430° to 600°C (800° to 1100°F). If desired, metals and glass can be recovered from the char after pyrolysis at this low temperature. Experience to date has been with a 4.5 metric ton/day (5 ton/day) pilot plant. Engineering design has been completed for a soon to be constructed 180 metric ton/day (200 ton/day) commercial plant in Long Beach, California. This commercial plant, however, will deal with nonmetallic waste from an automobile salvage operation rather than with MMR.

3.4.3.2.2 Barber-Colman (Ref. 3-56)

The Barber-Colman process reactor is a closed horizontal shaft with a circulating molten lead bed as the heat transfer media. (See Figure 3-54 for the process flow sheet). The refuse is first fed to a metal detector where large chunks greater than 15 centimeters (6 in.) are removed. The remaining material is then shredded to about 5 centimeters (2 in.) before being fed to the reactor via an air lock. The pilot plant reactor has a capacity of about 700 kilogram/day (1500 pound/day) and has dimensions of 1.8 meters (6 feet) length with a rectangular cross section of 25.4 centimeters (10 in.) depth and 45.7 centimeters (18 in.) width.

The refuse "floats" on the molten lead surface which is circulated via a gas lift pump. The lead bath is heated from the top by standard radiant tube burners located in the vapor space. The refuse is pyrolyzed from the lead surfacte at a temperature of about 650°C (1200°F), producing a gas with a target heating value of about 1.8 to 2.6 x 10^7 joules/meter^3 (500-700 Btu/SCF). About one-fourth of the gas will be used in the "gas lift" system. The remainder of the gas would be available for sale.

Some material will dissolve/settle in the lead bath and will have to be removed periodically by batch processing. Thus at desirable intervals, a portion of the lead bath will be withdrawn and reclaimed with corresponding addition of clean lead to the reactor. Inert materials

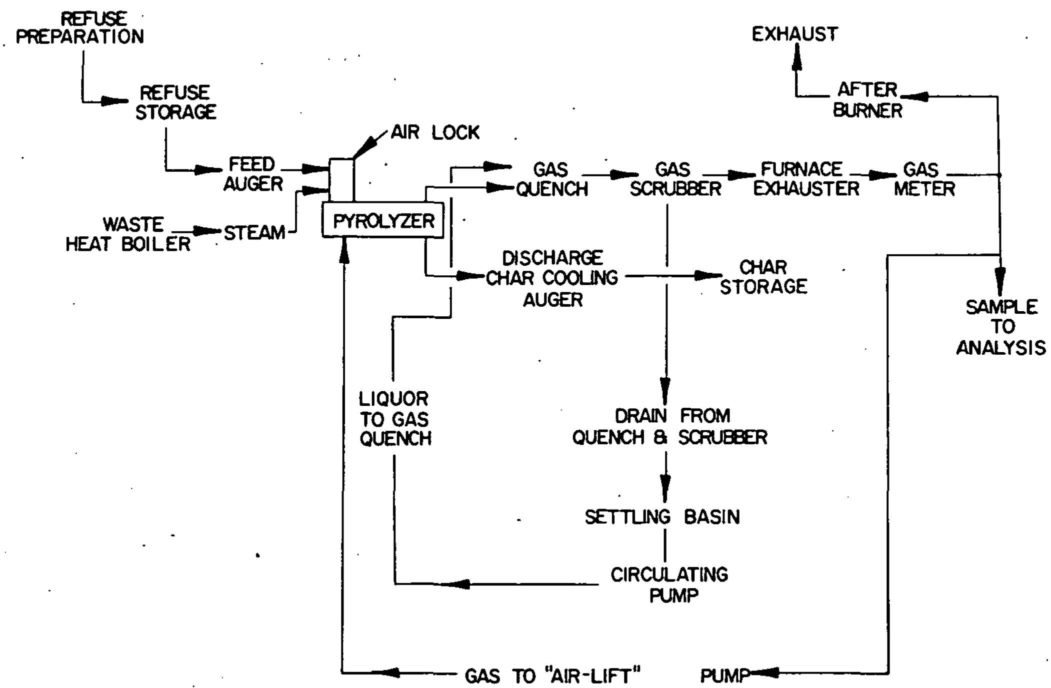


FIGURE 3-54
BARBER-COLMAN PYROLYSIS SYSTEM FLOW SHEET

that remain on the surface are removed by means of a mechanical rake device at the opposite end of the reactor from the refuse feed part. Some low pressure steam is generated in the process.

3.4.3.3 ROTARY KILN

3.4.3.3.1 Monsanto (Ref. 3-21, 3-22, 3-28, 3-47, 3-60, 3-61, 3-62)

The Monsanto "Landgard" process (Figure 3-55) has been tailored to meet

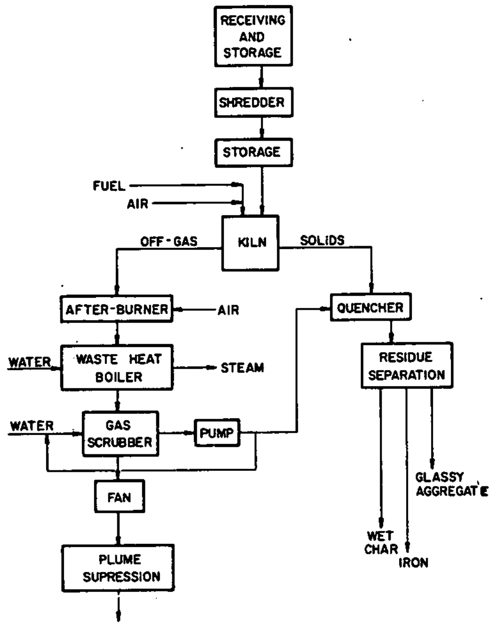


FIGURE 3-55
MONSANTO LANDGARD PYROLYSIS SYSTEM

the needs of the city of Baltimore where a 910 metric ton/day (1000 ton/day) plant is under construction. Shredded waste 10 centimeters (4 in.) in size is conveyed to a storage system from which it is continuously fed into a refractory-lined rotary kiln. A fired fuel (oil) and air stream are fed into the opposite end of the kiln. Countercurrent flows of gases and solids expose the refuse feed to progressively higher temperatures, 1000°C (1800°F) maximum, as it passes thru the kiln, so that first drying and then pyrolysis occurs. Hot residue is discharged from the kiln into a waterfilled quench tank. A conveyor then elevates the residue into a flotation separator. Light material floats off as a carbon char slurry, which is thickened and filtered to remove the water, then conveyed to a storage pile prior to truck transport from the site.

Heavy material is conveyed from the bottom of the flotation separator to a magnetic separator for removal of ferrous materials. Recovered metals are deposited either in a storage area, or directly into a railroad car or truck. The balance of the heavy material, now called a glassy aggregate, passes through screening equipment and is then stored on-site. This glassy aggregate can be used in building asphalt roads.

Pyrolysis gases are drawn from the kiln into a refractory-lined afterburner, where they are mixed with air and burned. The afterburner prevents discharge of combustible gases to the atmosphere and subjects the gases to temperatures high enough for destruction of odors.

Hot combustion gases from the gas purifier pass through water tube boilers, where heat is exchanged to produce steam. The steam will be used for heating and air conditioning of buildings in downtown Baltimore. Exit gases from the boilers are further cooled and cleaned of particulate matter as they pass through a water spray scrubbing tower. Scrubbed gases then enter an induced draft fan which moves the gases through the entire system. To suppress formation of a steam plume, the gases are passed through a dehumidifier in which part of the water is removed and recycled, and then the gases are discharged to the atmosphere.

Normally, all water leaving the system will be carried out with the residue, or evaporated from the scrubber. All process water is cleaned and recycled. Further details on this process will be presented in section 3.4.4.2.

3.4.3.3.2 Devco Management, Inc.

The largest system for MMR pyrolysis presently being constructed is the Devco plant in Brooklyn, New York. This 1360 metric ton/day (1500 ton/day), consists of five parallel 272 metric ton/day (300 ton/day) modules. The system is basically similar to the Monsanto system. Probably the most notable differences in the Devco System are lower temperatures, less than 540°C (1000°F) and less preprocessing. Rather than shredding, Devco uses a proprietary "selective pulverizer" which breaks up low tensile strength items in a low energy process. The differences in preprocessing and in processing temperature require Devco to use a somewhat larger rotary kiln than Monsanto would use for the same processing rate.

The Devco system provides steam (from combustion of the pyrolysis gas) and char, which can be fired with pulverized coal, as salable products. The saturated steam is produced at a rate of about 1.5 kilograms per kilogram of MMR and has an absolute pressure of 2.8×10^6 newtons/meter^2 (400 pound/in^2), whereas the char is produced at a rate of about 6 percent by weight of the MMR feed. This char has a heating value of about 2.3×10^6 joules/kilogram (10,000 Btu/pound) and produces less than 10 percent ash when burned.

3.4.3.3.3 Rust Engineering (Ref. 3-57, 3-58, 3-59)

Rust Engineering, a division of Wheelabrator - Frye, has been awarded part of a $10-million contract by the Metropolitan Sewer Board of the Twin Cities (Minneapolis-St. Paul) for the design and construction of a pyrolysis plant. The process is still in the design and development stages. The basic process (Figure 3-56)

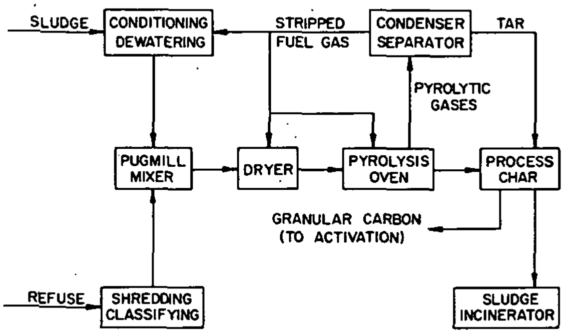


FIGURE 3-56
RUST ENGINEERING PYROLYSIS PROCESS SCHEMATIC

is a method of decomposing sludge in combination with solid refuse to recover carbon and fuel gas. The refuse is shredded, classified and dried and fed to the pyrolysis reactor where it is mixed with treated sewage sludge. Fuel gas from the reactor is recycled while char is used to incinerate other sludge or is activated and used in sewage treatment. An externally heated rotary kiln reactor will be used. Anticipated capacity is about 326 metric ton/day (360 ton/day), (28 percent sewage sludge and 72 percent refuse).

3.4.3.3.4 Pan American Resources (Ref. 3-8, 3-63, 3-64)

The Waste Conversion Systems Division of Pan American Resources, Inc. * has developed a pyrolysis system called the "Lantz converter". Little information is available. Mixed municipal refuse is fed continuously through a hammermill to a rotating stainless steel drum. External heating is used to heat the reactor to about 1100°C (2000°F). Natural gas is used as fuel for startup. Pyrolysis gases are then recycled to the burners during normal operation. Excess gas (about 30 percent) is flared, and there is char recovery.

*Pan American Resources, Inc. has terminated operations.

3.4.3.4 FLUIDIZED BED

3.4.3.4.1 West Virginia University (Ref. 3-65, 3-66, 3-67, 3-68)

Research on combustion and pyrolysis in fluidized beds at West Virginia University has led to a proposal for a two bed system for the pyrolysis of MMR (see Figure 3-57). The inert bed material (sand) would be circulated between the separate combustion and pyrolysis beds, carrying combustion heat to the pyrolysis bed and pyrolysis char to the combustion bed. Since air is excluded from the pyrolysis bed, the pyrolysis gas produced is relatively free of undesirable nitrogen. Such gas, with a heating value between 1.5 and 1.85×10^7 joules/meter^3 (400-500 Btu/SCF), is probably directly marketable to certain utility or industrial customers, and it also has the potential to be upgraded to pipeline quality methane. Temperatures of approximately 1000°C (1800°F) in the combustion bed and 760°C (1400°F) in the pyrolysis bed have been recommended. A portion of the pyrolysis gas is cleaned (probably after cooling) and recirculated by blowers as the fluidizing gas in the pyrolysis chanber. Preheated air for combustion of the char is used to fluidize the combustion bed. Further details on the process will be presented in section 3.4.4.4.

3.4.3.4.2 A. D. Little (Ref. 3-70)

A variation of the West Virginia University Process has been proposed by Arthur D. Little, Inc. and Combustion Equipment Associates, Inc. The most notable change proposed is substitution of dolomite for sand as the material in the fluidized beds. Use of dolomite significantly changes the heat transfer characteristics due to the carbon dioxide acceptor reaction. In the combustion reactor the dolomite ($MgO \cdot CaCO_3$) will absorb heat and release its carbon dioxide to the exhaust gases, then this calcined (or regenerated) dolomite ($MgO \cdot CaO$) will pass to the pyrolysis reactor. In the lower temperature and reducing atmosphere of the pyrolysis

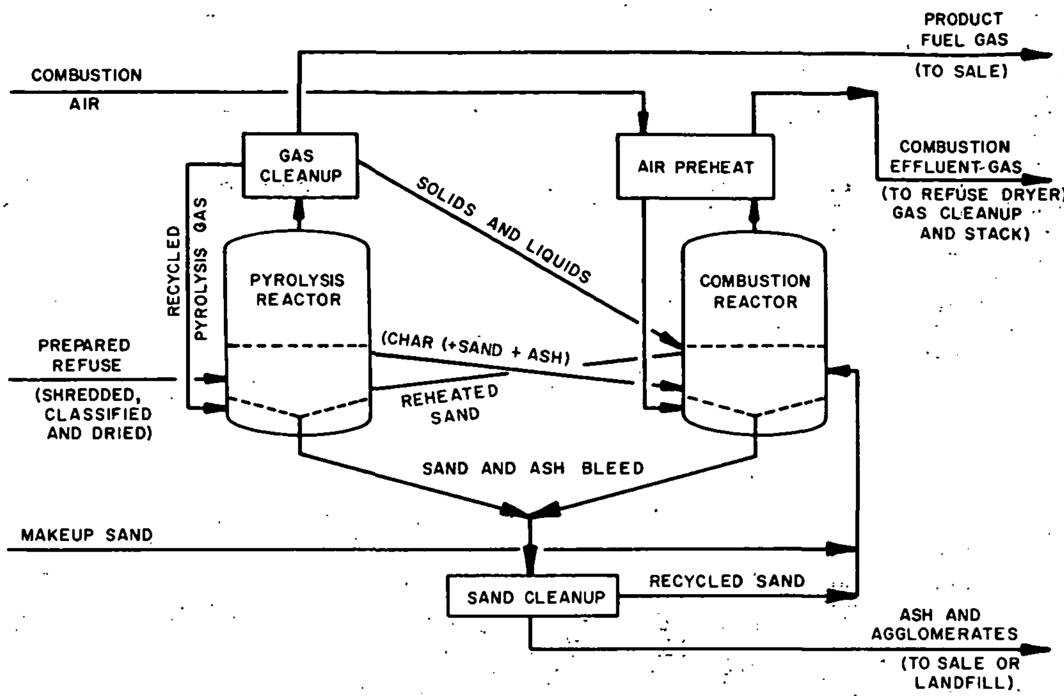


FIGURE 3-57
SCHEMATIC OF WEST VIRGINIA UNIVERSITY PYROLYSIS PROCESS

reactor the dolomite will accept carbon dioxide and release heat. Because of this carbon dioxide acceptor reaction, the heat needed in the pyrolysis reactor can be supplied with a smaller quantity of dolomite than sand. Also the removal of carbon dioxide from the pyrolysis gas via the acceptor process will improve the heating value of the gas somewhat. This improvement in heating value would not exceed 15 percent, however, since the West Virginia University pyrolysis gas contains only 15 percent carbon dioxide.

Another distinguishing characteristic of the A. D. Little proposal concerns the preprocessing of the MMR. They have proposed processing the MMR to Eco-Fuel™ (paragraph 3.2.4.2) before feeding it to the pyrolyzer. Such extensive pre-conversion processing should minimize difficulties within the reactors.

No experimental work has apparently been done using the carbon dioxide acceptor process for refuse pyrolysis. The extensive preprocessing of the MMR, however, makes the procedure rather similar to coal gasification. A carbon dioxide acceptor coal gasification pilot plant which produces 4.2×10^4 cubic meters (1.5×10^6 SCF) of gas per day is in operation in Rapid City, South Dakota.

3.4.3.4.3 Coors (Ref. 3-69)

Coors (Golden, Colorado) is conducting pilot plant work with the goal of generating gas from municipal refuse to fire process steam boilers. A 0.91 metric ton/day (1 ton/day) fluidized bed system has been tested with 5 centimeter (2 in.) shredding and air classification pre-processing. A screw conveyor is used to feed the reactor. The vessel is tapered with a 0.9 meter (3 feet) maximum diameter. Both indirect heating (superheated steam in tubes) and direct heating (partial oxidation in the same vessel) have been explored with the latter favored at the present time due to operationsl simplicity. The resultant lowered gas heating value is not considered a major problem since the product is not transported but burned on site. Normal pyrolysis temperature is about 760°C (1400° F) at a gage pressure of about 7×10^4 newtons/meter^2 (10 psi).

3.4.3.5 Other Pyrolysis Work

A significant amount of pyrolysis work on municipal refuse does not conveniently fall into the four reactor categories previously listed. Also, several systems have been inadequately described in the literature - some under the guise of "proprietary information". Several others are strictly research scale in nature. Typically, these projects investigate system subcomponents only and utilize research scale equipment. An example of the research type equipment might be electrically heated batch reactors, which would normally not be a viable method of reactor heating on a full scale plant. The research projects are normally used for establishing relationships between design and operating variables such as temperature and residence time, and system responses such as product distribution.

3.4.3.5.1 Battelle - N. W. (Molten Salt) (Ref. 3-71)

The Battelle molten salt process (Figure 3-58) research has been conducted in a 10 centimeter (4 inch) diameter Inconel reactor. A sodium carbonate bed was heated to temperatures between 870° and 980°C (1600° and 1800°F) by means of steam injection. Both surface and submerged refuse feeding were studied as well as ash-molten salt separation. It was concluded that the process was technically feasible, but economically impractical due to a required complex ash removal process. A conceptual plant design was proposed (Figure 3-59).

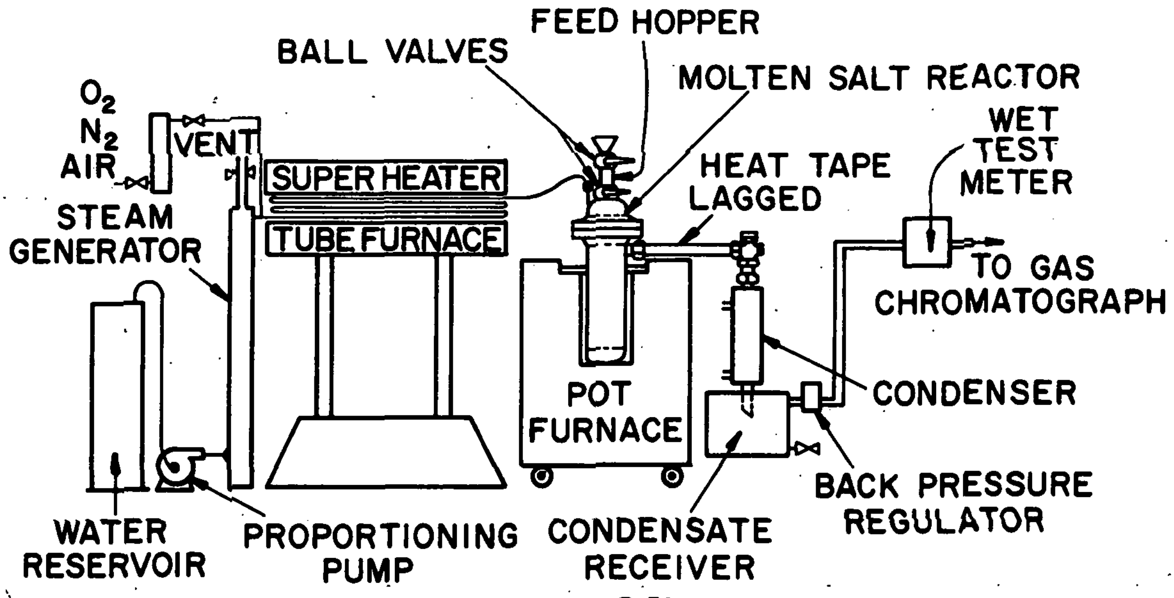


FIGURE 3-58
BATTELLE MOLTEN SALT LABORATORY REACTOR SCHEMATIC

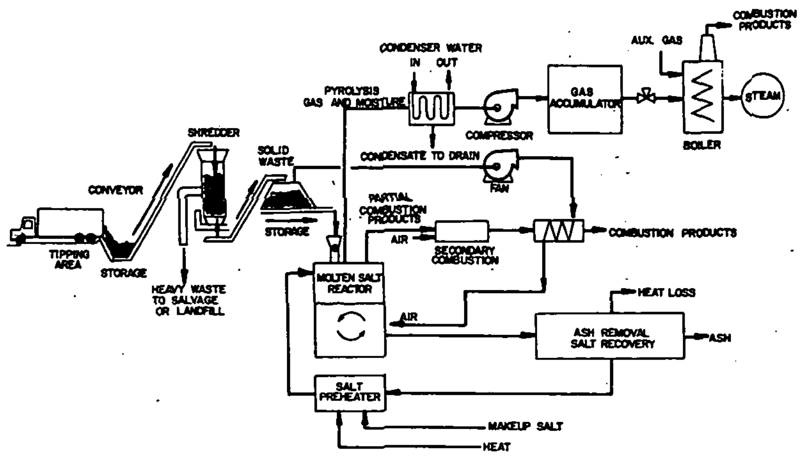


FIGURE 3-59
BATTELLE MOLTEN SALT PROCESS SCHEMATIC

3.4.3.5.2 Hercules (Ref. 3-28, 3-72)

Hercules, Inc., and a subsidiary company, Black, Crow and Eidsness, Inc., have done the preliminary design for a waste reclamation system for the State of Delaware. This 454 metric ton/day (500 ton/day) system will concentrate on production of humus (see Sec. 3.5.2 for description of similar processes), but pyrolysis will be used for reduction of material which cannot be composted. Initial study of the pyrolysis system involved fuel gas production from an indirectly heated fluidized bed reactor. Subsequently, however, it was decided to concentrate on char production using a Herreshoff furnace similar to the type sometimes used to produce charcoal. The Herreshoff furnace is a collection of circular hearths contained in a vertical shaft. Rotating arms are used to move the feed across any hearth to a port where it falls to the next hearth. Black, Crow and Eidsness personnel have reportedly performed experiments using both the fluidized bed and the Herreshoff furnace for pyrolysis, but the results and details of operation involving the heating method are not publicly available.

3.4.3.5.3 Bureau of Mines (Ref. 3-22, 3-28, 3-73, 3-74, 3-75)

The Bureau of Mines process is an adaptation of a coal gasification unit. Work to date has been conducted in small-scale batch processes (Figure 3-60). The reactor, containing 23 to 45 kilograms (50 to 100 pounds) of refuse, is placed in an electric heating mantle. Products of pyrolysis flow thru a product recovery train where tar, heavy oils, lighter oil, aqueous products and mists are removed. Alkali and acid wash towers remove gaseous products such as ammonia, hydrogen sulfide, carbon dioxide and hydrogen chloride. The remaining gases are measured and sampled after freezing out any remaining light oils. The pyrolysis reactor is 46 centimeters (18 inches) in diameter and 66 centimeters (26 inches) deep and is constructed of steel. A series of experimental runs has been conducted with various feed compositions and pyrolysis temperatures.

3.4.3.5.4 New York University (Ref. 3-76, 3-77)

E. R. Kaiser, while employed at New York University* conducted pyrolysis research with municipal refuse. A schematic of the apparatus is shown in Figure 3-61. The equipment consisted of a stainless steel reactor and series of cold traps. The reactor was operated in a batch mode with a capacity of 100 grams of refuse (shredded and dried) per run. The reactor was then externally heated to about 930°C (1700°F). Product distribution was studied as a function of heating rate.

*The Engineering School at NYU has been dissolved and pyrolysis research is no longer being conducted.

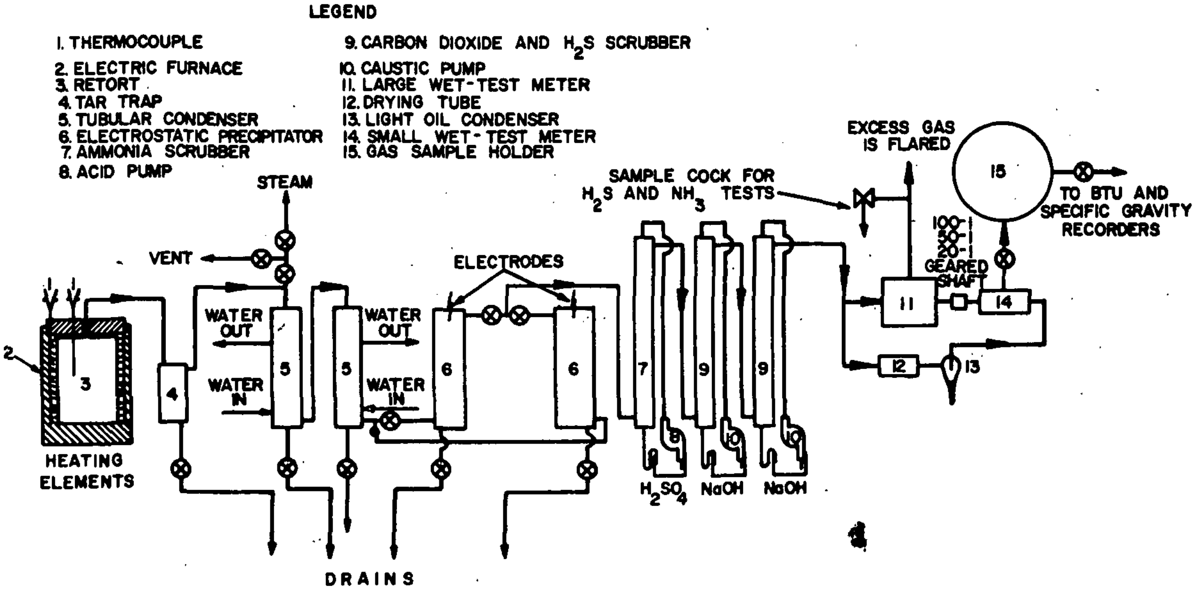


FIGURE 3-60
BUREAU OF MINES PYROLYSIS PROCESS SCHEMATIC

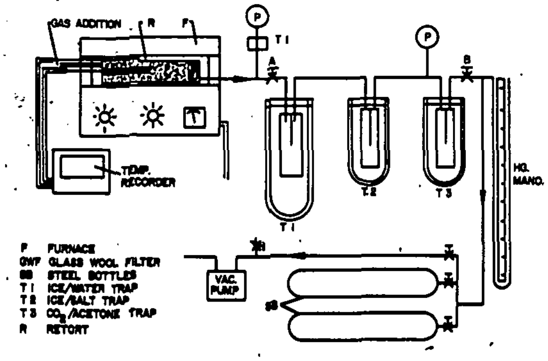


FIGURE 3-61
NYU APPARATUS SCHEMATIC

3.4.3.5.5 Univ. of Southern Calif.

The Department of Environmental Engineering at U.S.C. is in the early stages of a study of pyrolysis of a mixed sewage sludge - municipal refuse stream. The small, research scale reactor is electrically heated. Temperature and residence time are being manipulated in a parametric study to determine the effects on product distribution.

3.4.3.5.6 Anti-Pollution Systems (Ref. 3-78)

Some research has been performed by Anti-Pollution Systems, Inc., regarding the use of a molten salt bath for pyrolysis of refuse. No results of this research are publicly available, and no commercial plants have been constructed for pyrolyzing MMR. Small commercial plants 9 to 23 metric ton/day (10 to 25 ton/day) have been sold for hospital refuse and scrap yard refuse.

3.4.3.5.7 Univ. of California (Ref. 3-79)

The pyrolysis reactor in the University of California studies (Figure 3-62 consists of a vertical cylinder constructed from a 30.5 centimeter (12 inch) section of 7.6 centimeter (3 inch) diameter schedule 40, stainless steel pipe. Electrical heating was used. Shredded refuse was fed into the reactor via a screw conveyor and the product gases and residues were collected and analyzed. The effect of temperature (900°-1000°C or 1650°-1830°F) on product distribution was studied.

3.4.3.5.8 Wallace - Atkins (Ref. 3-80)

The Wallace-Atkins Oil Corporation process includes a pyrolysis reactor (horizontal shaft), electrolytic cell and fuel cell. The bacterial fuel cell is used to produce both electricity and methane from organic waste. The electricity then ionizes water into hydrogen and oxygen in an electrolytic cell. Hydrogen, refuse and methane are then fed to the pyrolysis reactor

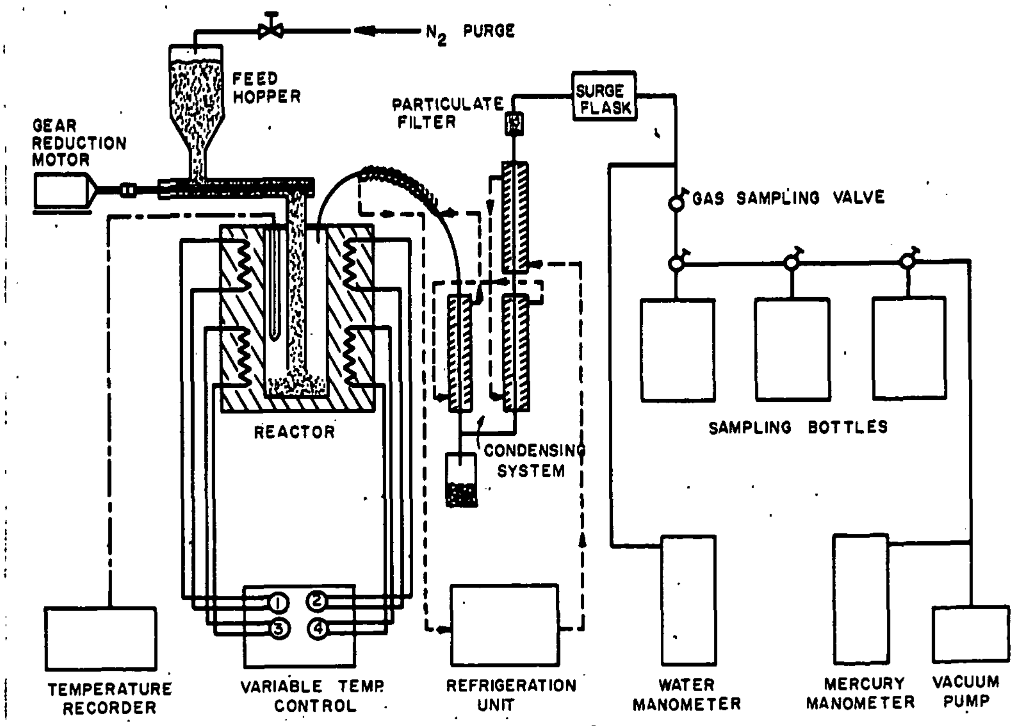


FIGURE 3-62
UNIVERSITY OF CALIFORNIA PYROLYSIS UNIT

to produce oil, gas and solid fuel. Process details are lacking. The company is negotiating with several sources to build a demonstration plant.

3.4.3.5.9 Resource Sciences (Ref. 3-47)

The Resource Sciences* resource recovery system pilot plant reactor consists of an electrically wrapped horizontal cylinder of 46 centimeters (18 inch) diameter and 3.8 meters (12.5 feet) length. Pilot plant capacity is 2.1 metric ton/day (2.3 ton/day). Gases and char are recovered while liquids are recirculated and injected with the refuse.

3.4.3.6 SELECTION OF PROCESSES FOR FURTHER ANALYSIS.

It was deemed desirable to choose a small number of pyrolysis systems for more detailed study than was possible for all the systems discussed previously. Several bases were used in this selection procedure. One goal was to select one representative from each major technical category, where sufficient information was available. In choosing between technically similar processes, emphasis was placed on the stage of development as evidenced by operation of pilot plants and contracts to construct commercial plants, and also on the amount of technical information available in the published literature.

Table 3-24 presents a classification of the various pyrolysis systems studied according to whether they use direct or indirect heating, the heat transfer method for indirect heating, the pyrolysis temperature used and the type of reactor used. Note that there is no column for slagging-temperature indirect heating systems since direct heating is the only practical way of achieving the temperatures greater than 1200°C (2200°F) for slagging. The pyrolysis systems largely fall into distinct groups within the table, and an effort was made to select for further study a representative of each major group.

As pointed out in Sec. 3.4.1.2, a vertical shaft is the simplest reactor type. Two systems of this type have been chosen for further study. The Union Carbide Purox process represents a system with direct heating and slagging of residue. Construction of the 180 metric ton/day (200 ton/day), commercial Union Carbide plant in Charleston, West Virginia represents the highest stage of development of a plant of this type. The Garrett process represents a vertical shaft with indirect heating. Again, a contract has been signed for construction of a commercial plant--the 180 metric ton/day (200 ton/day) plant in San Diego, California.

*Resource Sciences has terminated operations.

TABLE 3-24
PYROLYSIS PROCESS GROUPINGS

REACTOR TYPE	DIRECT HEATING NONSLAGGING	DIRECT HEATING SLAGGING	INDIRECT HEATING (nonslagging) WALL TRANSFER	INDIRECT HEATING (nonslagging) CIRC. MEDIUM
Vert. Shaft	Ga. Tech. Battelle	URDC Torrax Un. Carbide		Garrett
Horizon. Shaft			Kemp	Barber-Colman
Rotary Kiln	Monsanto Devco		Rust Pan. Am. Res.	
Fluid. Bed	Coors			West Va. Univ. A. D. Little

Several systems are being developed using indirect heating and the improved control of material flow provided by a horizontal shaft. None of these systems, to date, have received a contract to construct a commercial scale plant. Also, relatively little technical information is available for them. For these reasons none of the horizontal shaft systems have been recommended for further consideration in this study.

Two separate systems using direct heating at nonslagging temperatures in rotary kilns have received contracts to construct commercial units. A 1350 metric ton/day (1500 ton/day) Devco plant is being constructed in Brooklyn, New York. Also, a 910 metric ton/day (1000 ton/day) Monsanto Landgard plant is being constructed in Baltimore, Maryland. Of these two rotary kiln systems the Monsanto system was chosen for further study on the basis of availability of published technical information. This difference in the availability of information can at least partially be attributed to the fact that the use of EPA funds for the Baltimore plant brings into the public domain information which might otherwise be proprietary.

As with horizontal shafts, none of the fluidized bed pyrolysis systems have been developed to a commercial scale. In fact the fluidized beds have not yet been developed to full pilot plants using MMR. Considerable information is available on the research conducted by Bailie at West Virginia University. Also available are independent studies of the projected economics of commercial scale operations using the dual fluidized bed West Virginia process. Based on this information this fluidized bed process was recommended for further study.

3.4.4 Further Analysis of Selected Pyrolysis System Alternatives

3.4.4.1 UNION CARBIDE PROCESS

3.4.4.1.1 Technical Description (Ref. 3-28, 3-47, 3-48, 3-49)

Figure 3-63 presents a more detailed schematic of the reactor for the Union Carbide system, shown schematically in Figure 3-53. Handling of the MMR is minimal. A crane is used to lift MMR from a dumping pit and drop it into the feed hopper, from which it falls by gravity through the two-seal airlock and into the reactor. Experiments have shown that the continuous pyrolysis and oxidation processes are unaffected by the amount of feed material in the reactor so long as the bed

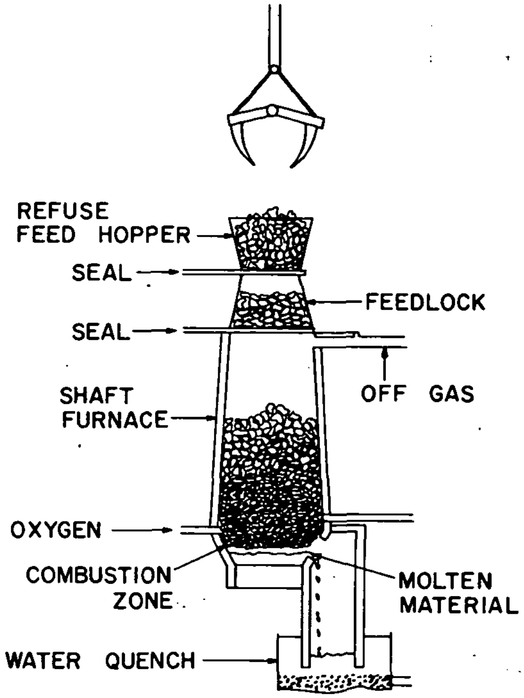


FIGURE 3-63
UNION CARBIDE REACTOR

depth is maintained between 0.9 and 2.1 meters (3 and 7 feet). Thus the "batch-type" feed system does not interfere with continuous processing in the reactor.

It has been found that the temperature gradient with height is much greater in the Union Carbide reactor than in the reactors of systems using preheated air. Essentially all of the drying, pyrolysis and combustion of the MMR occurs in the lower 0.9 meter (3 feet) of the Union Carbide reactor. The temperature at the 0.9 meter (3 foot) level is typically about 120°C (250°F) with temperatures between 1100° and 1650°C (2000°-3000°F), at the base of the reactor. This high temperature gradient presumably is due to the high heat transfer rates of oxygen-fuel flames, as compared to air-fuel flames. One advantage of the high temperature gradient is the fact that only the lowest portion of the reactor needs be lined with a refractory material, with an uncooled metal shaft being acceptable for the upper portion.

Another advantage of the high temperature gradient in the reactor is the fact that the Union Carbide pyrolysis gas leaves the reactor at about 93°C (200°F), compared to 315° to 430°C (600°-800°F) in the Torrax system (ref. 3-52). The lower temperature gas is much more convenient for handling in the gas clean-up train. Also, the 93°C (200°F) temperature results in relatively little loss in sensible heat of the gas.

Table 3-25 gives the composition of the Union Carbide pyrolysis gas after removal of water vapor and condensible hydrocarbons. Before passing through the electrostatic precipitator and the condenser the gas contains about 28 percent water and 3 percent condensible hydrocarbons and flyash. Since the material removed by the electrostatic precipitor is recycled to the high temperature zone of the reactor the liquid hydrocarbons are cracked or combusted so that liquid fuel is not an end product. One of the most desirable characteristics of the pyrolysis gas is its low nitrogen content, as contrasted with the gas of any system using direct heating with air as the oxidant. Nitrogen in a fuel gas is, of course, undesirable not only as a diluttant, but also as a source of NO_x pollution when the gas is burned. Even though the fuel gas is virtually nitrogen free and only contains 14 percent diluting carbon dioxide, it still has a heating value of only about 1.06×10^7 joules/meter^3 (286 Btu/SCF), since its primary constituents are carbon monoxide and hydrogen, both with low heating values. This is in contrast to gases from lower temperature pyrolysis which usually contain greater amounts of methane and heavier hydrocarbons. The gross energy reclamation from MMR by the Union Carbide process is about 8×10^9 joules/metric ton (7×10^6 Btu/ton) of MMR, but the oxygen production requires approximately one-third of this energy. The net energy reclamation is only about 5.3×10^9 joules/metric ton (4.7×10^6 Btu/ton). Assuming an energy content of approximately 11.5×10^9 joules/metric ton (10^7 Btu/ton), the Union Carbide process yields a net thermal efficiency of between 45 and 50 percent.

The only usable byproduct (in addition to the fuel gas) produced by this process is aggregate or frit (approximately 28 percent by weight of the MMR) resulting from quenching of the slag. Presently available technology does not seem to favor reclamation of usable metals or glass from this slag. Of course it would be possible to add prereactor processing for material recovery if justified by economic or other reasons.

Something of an amalgamation of the processes of Union Carbide and URDC has been proposed by Hamilton Standard (ref. 3-81). They suggested a staged development wherein a URDC system with heated air for oxidation would be constructed initially. Then at any subsequent time when the cost was justified an oxygen separation plant could be added, converting the system to the Union Carbide process.

TABLE 3-25
UNION CARBIDE FUEL
GAS COMPOSITION

CONSTITUENTS	VOLUME %
CO	47
H_2	33
CO_2	14
CH_4	4
C_2H_x	1
N_2	1
	100

It should perhaps be noted that after conversion to the Union Carbide system the URDC air preheater and some of the insulation and refractory material of the URDC reactor would not be needed.

The pollution problems of the process are considered to be very minimal. The only effluents from the plant are the fuel gas, the inert slag, and clean water condensed from the fuel gas. Further, the fuel gas is quite "clean" (low NO_x and SO_x, in particular) and should present no special pollution problems when burned. The primary social concern relating to installation of a Union Carbide plant in a community is apt to be related to the potential safety hazard of producing and using pure oxygen.

3.4.4.1.2 Economic Data

The economic data given in the following Process Cost Data and Resource Recovery Data forms, Table 3-26, are taken from ref. 3-2 and 3-21.

The economic data for the 1814 metric ton/day (2000 ton/day) plant is based on 365 days per year operation. The credits received are primarily from fuel gas at \$0.71/10^9 joules (\$0.75/10^6 Btu). The pyrolysis gas is assumed to have a heating value of approximately 1.12×10^7 joule/meter^3 (300 Btu/SCF). Considerable additional treatment would be needed before it could be used as pipeline gas in interstate commerce; however, local sales should be possible. Fused metal and glass frit is recovered at the rate of 20 tons per 100 tons of MMR and is credited at the rate of \$2.00 per ton. No credit is given for metal recovery in this process (ref. 3-21).

The economic data for the 907 metric ton/day (1000 ton/day) plant is based on 300 days/year operation. Credit for the sale of gas is given at \$0.47/10^9 joules (\$.50/10^6 Btu). It is estimated that 75 percent of the assumed 1.049×10^7 joules/kilogram (4500 Btu/pound) heating value of refuse is recovered. Labor costs are

TABLE 3-26
ECONOMIC DATA-UNION CARBIDE SYSTEM
PROCESS COST SHEET

PROCESS NAME: Union Carbide
DATA SOURCE: Reference 3-21
CAPACITY IN TONS/DAY: 1814 metric tons (2000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities		
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	$24,400,000	
OPERATING COSTS ($ PER YR)		
Maint. Material		
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead		
Utilities		
Taxes		
Insurance		
Interest		
Disposal of Residue		
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	$ 3,255,800	Based on 365 Days/Yr Operatio.
CREDITS ASSUMED ($ PER YR)	$ 4,015,000	

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid		
Gas	$ 3,723,000	
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals		
Nonmagnetic Metals	292,000	Based on $2.21/ metric ton ($2/ton)
Glass		
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	$ 4,015,000	

TABLE 3-26 (CONTINUED)

PROCESS NAME: Union Carbide
DATA SOURCE: Reference 3-2
CAPACITY IN TONS/DAY: 907 metric tons (1000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land	$ 150,000	
Preprocessing Eqmt)		
Processing Eqmt)		
Postprocessing Eqmt)	9,450,000	
Utilities)		
Building & Roads)		
Site Preparation	150,000	
Engr. & R & D	450,000	
Plant Startup	214,000	
Working Capital	320,000	
Misc.:		
TOTAL	$10,734,000	
OPERATING COSTS ($ PER YR)		
Maint. Material		
Maint. Labor)	$ 623,000	@ $5/hr
Dir. Labor)		
Dir. Materials	45,000	
Overhead	171,000	
Utilities	425,000	
Taxes		
Insurance		
Interest		
Disposal of Residue		
Payroll Benefits	187,000	@ 30% of Labor
Fuel		
Misc.:		
TOTAL	$ 1,451,000	
CREDITS ASSUMED ($ PER YR)	$ 1,200,000	

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid		
Gas	$1,020,000	@ $0.47/10^9 joules ($.50 per MM Btu) 1.12 x 10^7 J/SCM Approximately (300 Btu/SCF)
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals		
Nonmagnetic Metals		
Glass	180,000	$3.31/metric ton ($3 per ton)
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	$1,200,000	

calculated at $5.00 per hour and payroll benefits at 30 percent of labor (ref. 3-2).

3.4.4.2 MONSANTO PROCESS

3.4.4.2.1 Technical Description (Ref. 3-21, 3-22, 3-28, 3-47, 3-60, 3-61, 3-62)

Monsanto's Landgard process is a two-stage combustion, pyrolysis system using supplemental fuel (see figure 3-55 for the process flow sheet). A waste heat recovery boiler can be added to produce steam. In the Landgard process, refuse is delivered to the disposal plant in packer trucks. The refuse is stored on a concrete pad, reclaimed with front-end loaders and fed directly to either of two 907 metric ton/day (1000 ton/day) horizontal shaft hammermills which reduce the refuse to 7.6-10 centimeters (3-4 inches) and which will be operated on an 8-hour shift. Provision has been made for a third shredder. After shredding, the refuse is conveyed to storage. From here the shredded refuse is fed continuously to the refractory lined rotary kiln.

Pyrolysis takes place in the kiln at 650°-980°C (1200°-1800°F), with air and fuel added at the discharge end of the kiln. A counter current flow of gases and solids exposes the feed to progressively higher temperatures as it passes through the kiln, so that drying first occurs followed by pyrolysis. The finished residue is exposed to the highest temperature just before it is discharged from the kiln. The kiln has been designed to expose solid particles uniformily to high temperatures before they are discharged to maximize the pyrolysis reaction.

The hot residue at 980°C (1800°F) is discharged from the kiln into a water-filled quench tank from which a conveyor elevates the wet residue into a flotation separator. Light material floats off as a carbon char slurry and is thickened and filtered to remove the water. Clarified water and filtrate are recycled for reuse. Carbon char is conveyed to a storage pile prior to truck transport to a landfill. Heavy material is conveyed from the bottom of the flotation separator to a magnetic separator for removal of iron, which is either deposited in a storage area or is deposited directly into a rail car or truck. The balance of the heavy material, glassy aggregate, passes through screening equipment and is then stored on-site.

Pyrolysis gases at 650°C (1200°F) are drawn from the kiln into a refractory lined gas purifier where they are mixed with air and fuel and burned. The gas purifier prevents discharge of combustible gases to the atmosphere and subjects them to temperatures high enough to destroy odors.

Hot combustion gases from the gas purifier pass through water tube boilers where heat is exchanged to produce steam. Exit gases from the boilers are further cooled and cleaned of particulate matter as they pass through a water spray scrubbing tower. Provisions are included to allow gases exiting from the gas purifier to completely or partially bypass the boilers and enter the scrubber tower directly.

Scrubbed gases then enter an induced draft fan which provides the motive force for moving the gases through the entire system. Gases exiting the induced draft fan are saturated with water. To suppress formation of a steam plume, the gases are passed through a dehumidifier in which they are cooled (by ambient air) as part of the water is removed and recycled. Cooled process gases are then combined with heated ambient air just prior to discharge from the dehumidifier.

Solids are removed from the scrubber by diverting part of the recirculated water to a thickener. Underflow from the thickener is transferred to the quench tank, while the clarified overflow steam is recycled to the scrubber.

Normally all the water leaving this system would be discharged with the residue or evaporated from the scrubber. An occasional process upset may allow too much water into the system and make it necessary to purge the excess. This purge stream will be discharged to the sanitary sewer at a maximum flow of 285 liter/minute (75 gallon/minute).

A total of 27 liters (7.1 gallons) of No. 2 fuel is used per 0.91 metric ton (1 ton) of refuse; 88 percent of the fuel is fed to the pyrolyzer and 12 percent to the gas purifier. Forty percent of the air required for stoichiometric combustion of the refuse is fed to the kiln.

The yield of products from 0.91 metric ton (1 ton) of refuse is as follows:

1. Steam - About 220 kilograms (4800 pounds) of saturated, low-pressure, low-temperature steam. In Baltimore, this steam is valued at \$1.80/1000 kilogram (\$0.81/1000 pounds). Assuming the steam contains 2.5 x 10^6 joules/kilogram (1100 Btu/pound), the total amount of recovered heat is about 6.1 x 10^{10} joule/metric ton (1 x 10^7 Btu/ton) and the 27 liters (7.1 gallons) of fuel oil another 1 x 10^9 joule (1 x 10^6 Btu), the overall thermal efficiency is 48 percent.

2. Ferrous Scrap - Ferrous scrap valued at $7.6/metric ton ($7/ton) can be recovered at a rate of about 5-7 percent of MMR weight.

3. Glassy Aggregate - About 155 kilograms (340 pounds) of glassy aggregate, which is suitable for use as clean fill, or possibly as a filler in building materials, and valued at $2.2/metric ton ($2/ton), will be produced.

4. Char - About 72 kilograms (160 pounds) (on a dry basis) of char is produced. The char is 46 percent glass and ash, 50 percent carbon, 3.5 percent volatiles and 0.2 percent sulfur. Its heating value is about 1.6 x 10^7 joules/kilogram (7000 Btu/pound). The char produced at Baltimore is 50 percent water, is assumed to have no value, and will be landfilled.

Monsanto has operated a 32 metric ton/day (35 ton/day) pilot plant for two years. Typical analyses of feed and products are given in Table 3-27. Its 910 metric ton/day (1000 ton/day) demonstration plant in Baltimore is scheduled for start-up in Fall, 1974. As the technology is relatively well developed, start-up should proceed relatively smoothly. If residue recovery is desired, a big area of uncertainty is likely to be the quality and quantity of the glassy aggregate and char and their market values. Difficulties may also be encountered with the disposal of water in the scrubbing and back end treatment circuits.

TABLE 3-27
MONSANTO LANDGARD
PROTOTYPE PERFORMANCE RESULTS

FEED ANALYSIS (AS RECEIVED)
(Wt. percent)

Proximate Analysis		Ultimate Analysis	
Moisture	20.8	Metal (Fe)	7.0
Volatiles	44.8	Glass + Ash	19.3
Fixed Carbon	8.1	Water	20.8
Inerts	26.3	Carbon	25.1
		Sulfur	0.3
		Hydrogen	3.0
		Nitrogen	0.4
		Oxygen	24.1

Higher Heating Value (Wet Basis = 1.067 x 10^7 joules/kg (4600 Btu/lb)

TABLE 3-27 (CONTINUED)

KILN OFF-GAS ANALYSES

(Vol. percent Dry Basis)	(Based on 27 Sample Runs)
Nitrogen	69.3
Carbon Dioxide	11.4
Carbon Monoxide	6.6
Hydrogen	6.6
Methane	2.8
Ethylene	1.7
Oxygen	1.6

RESIDUE ANALYSIS
(Wt. percent Dry Basis)

Proximate Analysis		Ultimate Analysis	
Volatiles	5.5	Metal (Fe)	21.9
Fixed Carbon	12.5	Glass + Ash	60.1
Inerts	82.0	Carbon	14.5
		Sulfur	0.1
		Hydrogen	0.5
		Nitrogen	0.2
		Oxygen	2.7

Higher Heating Value .570 x 10^7 joules/kg (2500 Btu/lb)(metal-fre

pH - 12.0

Water soluble solids 2 percent

Putrescibles 0.1 percent (Enviro-Chem Analytical Method based on standard 5 day BOD test)

EFFLUENT GAS ANALYSIS
(Vol. percent Dry Basis)

Nitrogen	79.2
Carbon Dioxide	8.0
Oxygen	12.8

Average analysis of effluent gas pollutants was:
Particulate 6.2 x 10^{-5} Kg/m^3
(0.027 grains/SCF dry gas)

CARBON CHAR PROPERTIES
Properties of the Carbon Char are:

Moisture 65 Percent by Wt.

Dry Basis	Wt. Percent
Volatile	4.0
Carbon	50.0
Ash (Ash & Glass)	45.8
Sulfur	0.2
Total	100.0

Bulk Density 320 - 800 kg/m^3 (20 - 50 lbs/ft^3)

Absorption Activity 430 m/g

TABLE 3-27 (CONTINUED)

Size

U.S. Mesh	Percent Retained
+18	25
-18 + 50	40
-50 + 100	12
-100 + 230	9
-230	14

Ferrous Metal Properties

Iron	98.85 Percent by Wt.
Impurities	1.15 Percent by Wt.

Glassy Aggregate Properties

Bulk Density	1442 Kg/m^3 (90 lbs/Ft^3)

Composition	Wt. Percent
Glass	65
Ferrous Metal	3
Non-Ferrous Metal	2
Carbon	2
Rock & Misc.	28

3.4.4.2.2 Economic Data

Projected economic cost studies as reported in Schulz, et.al., (ref. 3-21). The referenced report contains a detailed explanation of the assumptions and some of these are noted below:

Interest rate	6.5%
Useful life assumed	15 years
Environmental Impact	Stack emissions and solid residue
Net credit given for recovery of metal	\$11/metric ton (\$10/ton)
Land Cost	Not specified
Waste Residue	118 metric ton/day (130 ton/day)

This report does not specify any transportation cost associated with the ferrous metals recovered, but current plans indicate that they will be transported from Baltimore to St. Louis, Missouri.

The next two sets of data are updates to reflect increasing energy costs. These costs were received from EPA in a June, 1974, telephone conversation with Mr. David Sussman, EPA Project Monitor for Landgard.

Amortized interest rate	6%
Useful life	20 years
Cost of #6 fuel oil	\$0.07/liter (\$11.00/barrel)

The final cost table relating to the Monsanto system was taken from a study done for Monroe County, Rochester, N.Y. in 1971. No detail costs were given, but the 1971 figures indicate a cost of \$12.67/metric ton (\$11.49/ton), but this does not provide for any credits for recovered products.

3.4.4.3 GARRETT PROCESS

3.4.4.3.1 Technical Description (Ref. 3-18, 3-21, 3-22, 3-28, 3-47, 3-50, 3-51)

The process of the Garrett Research and Development Company, the research organization supporting the Occidental Petroleum Corporation, was developed as a spin-off of its coal-conversion research. See Figure 3-48 for the flow schematic. The process incorporates the following features:

1. an extensive pretreatment and drying system,
2. rapid heating and pyrolysis (short residence time),
3. condensation of gaseous pyrolysis products to yield a hydrocarbon vapor fraction, a hydro-liquid fraction, and water,
4. most likely, recycling of solid products to facilitate heat transfer.

A pilot facility with a capacity of about 3.6 metric ton/day (4 ton/day) has been in operation at Garrett, and results presented below are based on the performance of this plant.

Garrett is presently constructing a 181 metric ton/day (200 ton/day) demonstration plant for the pyrolysis of refuse for San Diego County under an EPA grant. In this process, refuse from packer trucks is dumped into a pit and reclaimed with a strip loader. The refuse is discharged onto a conveyor with facilities for hand-sorting material of value and material too heavy to shred. The refuse is then fed to a primary shredder and cut up into pieces of about 2.5 centimeters (1 inch).

The shredded material is classified in three stages using, first, a zig-zag air classifier which reduces the inorganics in the light fraction to about 10 percent and, second, using a two-deck screen with 0.63 centimeters (0.25 inch) and 14-mesh openings to reduce the inorganics in the light fraction to about 2 percent. Finally, the light fraction is dried in a rotary drier to about 3 percent moisture after the air classifier but before the screen classifier operation. The clean organic fraction is then shredded

TABLE 3-28 (A)
ECONOMIC DATA-MONSANTO LANDGARD SYSTEM

PROCESS NAME: Monsanto Landgard
DATA SOURCE: Reference 3-21
CAPACITY IN TONS/DAY: 907 metric tons (1000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities	14,700,000	
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	14,700,000	
OPERATING COSTS ($ PER YR)		
Maint. Material		
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead		
Utilities		
Taxes		
Insurance		
Interest	2,418,000	Based on $8.87/metric ton x 907 metric ton/day x 300 days/year (Based on $8.06/ton x 1000 tons/day x 300 days/year)
Disposal of Residue		
Payroll Benefits		
Fuel		
Misc.: Disposal of Water Residue	195,000	
TOTAL	2,613,000	
CREDITS ASSUMED ($ PER YR)	$4.22/metric ton ($3.83/ton)	

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam	1,164,000	
Electricity		
Hot Water		
Magnetic Metals	210,000	
Nonmagnetic Metals		
Glass	75,000	Vitreous Frit
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	1,449,000	

TABLE 3-28 (B)

PROCESS NAME: Monsanto Landgard
DATA SOURCE: January, 1973, estimates obtained from David Sussman of EPA in June, 1974. (telephone conversation
DAPACITY IN TONS/DAY: 907 metric tons (1000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities		
Building & Roads		
Site Preparation		
Engr. & R & D	14,742,000	
Plant Startup		
Working Capital		
Misc.:	126,000	
TOTAL	14,868,000	
OPERATING COSTS ($ PER YR)		
Maint. Material	552,000	
Maint. Labor		
Dir. Labor	306,000	
Dir. Materials	93,000	Water and Chemicals
Overhead		
Utilities	318,000	Electricity
Taxes		
Insurance		
Interest		
Disposal of Residue	54,000	Char removal
Payroll Benefits		
Fuel		
Misc.:	267,000	
TOTAL	1,590,000	

CREDITS ASSUMED ($ PER YR)

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam	1,167,000	
Electricity		
Hot Water		
Magnetic Metals	132,000	
Nonmagnetic Metals		
Glass	102,000	
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	1,401,000	

TABLE 3-28 (c)

PROCESS NAME: Monsanto Landgard
DATA SOURCE: February, 1974 estimates obtained from David Sussman of EPA in a telephone conversation, June, 1974.
CAPACITY IN TONS/DAY: 907 metric tons (1000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities	14,742,000	
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:	120,000	
TOTAL	14,862,000	(Use 6% & 20 yrs to amortise)
OPERATING COSTS ($ PER YR)		
Maint. Material	570,000	
Maint. Labor		
Dir. Labor	330,000	
Dir. Materials	90,000	Water & Chemicals
Overhead		
Utilities	390,000	Electricity
Taxes		
Insurance		
Interest		
Disposal of Residue	60,000	Char Removal
Payroll Benefits		
Fuel	600,000	
Misc.:		
TOTAL	2,040,000	

CREDITS ASSUMED ($ PER YR) $7.94/metric ton ($7.20/ton)

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam	3,450,000	
Electricity		
Hot Water		
Magnetic Metals	300,000	
Nonmagnetic Metals		
Glass	120,000	
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	3,870,000	

TABLE 3-28 (D)

PROCESS NAME: Monsanto Langard
DATA SOURCE: Reference 3-82
CAPACITY IN TONS/DAY: 907 metric tons (1000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities		
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL		
OPERATING COSTS ($ PER YR)		
Maint. Material		
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead		
Utilities		
Taxes		
Insurance		
Interest		
Disposal of Residue		$8.82/metric ton ($8.00/ton) plus amortization of plant and site yields $12.67/metric ton ($11.49/ton) gross disposal cost.
Payroll Benefits		
Fuel		
Misc.:		
TOTAL		
CREDITS ASSUMED ($ PER YR)		

to about 28 mesh size. The overall power requirements are about 82 kilowatt per metric ton (100 horsepower per ton), equally split between the two stages.

The finely shredded refuse is flash-pyrolyzed at about 480°C (900°F). The pyrolysis products pass through a cyclone for char removal and are cooled using a direct-contact water condenser. The oil is removed as a liquid and the moderate heating value gas, $1.9\text{-}2.2 \times 10^7$ joule/meter^3, (500-600 Btu/feet^3) is recycled for process heat. An unspecified portion of the char is also used for process heat. The waste water, containing a variety of organic compounds, must also be treated prior to disposal.

Garrett has not revealed the reactor heat transfer method used in their process. However, it is quite likely that the system is very similar to that described in the patent literature for the coal gasification version of their pyrolysis process (ref. 3-83). In this process, hot recycled char is transported into the reactor bottom by recycled gas. Upon contact with the hot char, the refuse is rapidly heated to its decomposition temperature as it is blown at high velocity through the reactor. Residence times of 0.1 to 3 seconds are claimed. The reactor products consist of volatized hydrocarbons and char solids. The gas is separated from the solids by means of a device such as a cyclone or electrostatic precipitator. The solids are then conveyed by means of an air stream through a heater where the air partially oxidizes the char and heats it to an elevated temperature. Alternately, the char may be heated by utilizing a shell and tube heat exchanger. The heated char is then passed thru another gas-solid separator twice after which it is picked up by the gas recycle stream and conveyed to the reactor.

The heavy inorganic fraction from the air classifier and screen is further screened to recover organics, which are then recycled to the process. The ferrous metals are recovered magnetically, with the remaining inorganics fed to a wet classifier in which the very fine particles (mostly silica) are removed. The washed material is then sent to a flotation unit and a relatively pure glass fraction is recovered. It is not clear how the non-ferrous metals are recovered, if at all, in the Garrett Process.

The products which can ultimately be recovered using this process are shown in Table 3-29. Presently, the only inorganics recovered are the ferrous metals and glass. No data are given on the quality of the ferrous metals. The glass fraction is reportedly of high purity; it is color-mixed and of sand size. Test melts with this material have shown none of the defects commonly reported when using reclaimed glass. A more detailed description of the Garrett preconversion system has previously been presented in section 3.2.4.3.

The quantities of gas, liquid, and char produced may vary considerably with feed sample and process conditions, as judged by the range of product mix reported by Garrett, even in a single article. The data in Table 3-29 represents one estimate of the product mix.

The physical and chemical properties of the oil fraction and that of a typical No. 6 are shown in Table 3-30. The py-

TABLE 3-29
RECOVERABLE PRODUCTS AND ENERGY -
GARRETT PYROLYSIS PROCESS

Recoverable Products

	As Received Composition (% by wt)	Estimated Recovery (%)	Recovered Products (% by wt)
A. Inorganic Products			
Magnetic Metals	6-8	95	5.7 - 7.6
Non-magnetic Metals	1-2	95	0.9 - 1.9
Glass	6-10	80	4.8 - 8.0
Dirt & Debris	2-4		
B. Organic Products	50-60		
Pyrolytic Oil		40	20 - 24
Pyrolytic Char		30	15 - 18
Pyrolytic Gas		20	10 - 12
Moisture		10	10 - 10

Recoverable Energy

	Joule/metric ton	Btu/ton	Joule/metric ton	Btu/ton
Energy Available	11.64×10^9	10,000,000	11.64×10^9	10,000,000
Energy in Product				
Pyrolytic Oil	4.89×10^9	4,200,000	5.85×10^9	5,040,000
Pyrolytic Char	3.14×10^9	2,700,000	3.77×10^9	3,240,000
Pyrolytic Gas	0.86×10^9	740,000	1.03×10^9	888,000
	8.89×10^9	7,640,000	10.65×10^9	9,168,000
Energy Consumed in Process				
100% of Pyrolytic Gas	0.86×10^9	740,000	1.04×10^9	888,000
25% of Pyrolytic Char	0.79×10^9	675,000	0.94×10^9	810,000
	1.65×10^9	1,415,000	1.98×10^9	1,698,000
Net Energy Produced				
Pyrolytic Oil	4.89×10^9	4,200,000	5.87×10^9	5,040,000
Pyrolytic Char	2.36×10^9	2,025,000	2.83×10^9	2,430,000
	7.25×10^9	6,225,000	8.70×10^9	7,470,000

TABLE 3-30
PHYSICAL AND CHEMICAL PROPERTIES OF OIL FRACTIONS

		No. 6	Pyrolytic Oil
Carbon	Percent by Weight	85.7	57.5
Hydrogen	Percent by Weight	10.5	7.6
Sulfur	Percent by Weight	0.5-3.5	0.1-0.3
Chlorine	Percent by Weight		0.3
Ash	Percent by Weight	0.01-0.5	0.2-0.4
Nitrogen	Percent by Weight		0.9
Oxygen	Percent by Weight	2.0	33.4
Energy		4.24×10^7 joules/kg (18,200 Btu/lb)	2.45×10^7 joules/kg (10,500 Btu/lb)
Specific Gravity		0.98	1.3
Viscosity SSU @ 88°C (190°F)		340	3,150

rolytic oil is acidic and may require treatment to permit storage in steel tanks. Its ash content may dictate the need for a cleanup system. Burners may require revision before this oil can be fired.

The gas has a heating value of about $1.9-2.2 \times 10^7$ joule/meter^3 (500-600 Btu/foot^3), and its composition (on a mole basis) is given in Table 3-31.

TABLE 3-31
GARRETT PYROLYSIS
GAS COMPOSITION

Gas	Mol. %
Carbon Monoxide	42.0
Carbon Dioxide	27.0
Hydrogen	10.5
Methane	5.9
Ethane	4.5
C_3-C_7 Hydrocarbons	8.9
Methyl Chloride	0.1
Water	< 0.1

This gas is presently consumed in the process, but it could be burned for the recovery of heat.

The char is a high-ash, low-heating value solid, which may be used as a fuel or perhaps as activated carbon. Presently, a portion of the char is used for process requirements. The composition of the char is given in Table 3-32.

The principal area of uncertainty in the Garrett process is the pyrolysis step. Much more information is required on the yield and composition of the three products. It appears that all pyrolysis work to date has been done using material from the Black-Clawson plant in Franklin, Ohio. (See Section 3.2.4.4 for a discussion of Black-Clawson process.)

There are also several potential problems concerning the most important

TABLE 3-32
GARRETT PYROLYSIS
CHAR COMPOSITION

Constituent	Weight %
Carbon	48.8
Hydrogen	3.9
Nitrogen	1.1
Sulfur	0.3
Ash	31.8
Chlorine	0.2
Oxygen (by difference)	13.9

product, the oil fraction:

1. Possible treatment to adjust the pH to permit storage in steel equipment;
2. The need for air pollution control equipment because of the high ash content of the oil;
3. The ability to burn this oil in gas/oil boilers using standard burners.

Development work is also required on the process for recovering non-ferrous metals. Garrett has reported no work in this area to date.

Garrett's present position is that it will design and construct a front-end processing plant now, but will not offer a pyrolytic unit for sale until the San Diego plant has operated successfully.

3.4.4.3.2 Economic Data

The economic data given in the following Process Cost Data and Resource Recovery forms are taken from the Schulz, et.al., report (ref. 3-21) from the MRI report (ref. 3-2) and from Mallan and Finney (ref. 3-51).

In ref. 3-21 the economic data is based on 365 days per year operation. One of the major differences between the economic data presented here and that presented in other sources is the amount of credit given for resources recovered. The magnetic metals are credited at $1.00/metric ton ($10.00 per ton) with 6.6 tons of metal recovered per 100 tons of MMR. Glass cullet is credited at $5.51/metric ton ($5.00/ton) with 5.6 tons recovered per 100 tons of MMR. Schulz questions whether the byproduct credit for glass cullet will offset the incremental processing cost necessary to obtain it. Energy credits are given at $0.10/liter ($15.35/barrel) of oil. This appears high in light of the fact that the oil contains only 2.45×10^7 joules/kilogram (10,500 Btu/pound) roughly 60 percent of the heating value of #6 fuel oil. Waste disposal is assumed to cost $5.51/metric ton ($5.00/ton) with 12.8 tons of waste per 100 tons of MMR. Table 3-30(a) gives the economic data for the study prepared for the city of New York in 1973.

The economic data given in ref. 3-2 assumes 300 days of operation and credits for the liquid oil, ferrous metals, and glass. The economics of various plant sizes are also given ranging from 227 metric ton (250 ton) capacity to 1814 metric ton (2000 ton) capacity. Table 3-30 (b) gives the MRI estimates.

Mallan and Finney (ref. 3-51) base their costs on 350 day/year and 24 hour/day operation. Shredding is estimated at $1.76/metric ton ($1.60/ton) and all gas produced is burned on site for process heat. Table 3-30(c) lists the estimates of ref. 3-51.

3.4.4.4 WEST VIRGINIA UNIVERSITY (BAILIE) PROCESS

3.4.4.4.1 Technical Description (Ref. 3-65, 3-66, 3-67, 3-68)

Because of the lack of operational data from a complete pilot plant many questions concerning the West Virginia University (WVU) process are yet unanswered. One may anticipate that the greatest difficulties will probably be associated with moving the hot sand between the two reactor chambers and with removal of ash and other inert material from the sand. Of course the chemical industry has had considerable experience with fluidized beds, but they have not used such a heterogeneous feed material with such a content of inert solids as will be the case with MMR.

One result of Bailie's tests with raw MMR was the fact that preprocessing is necessary to remove at least some of the metal and glass. Clogging of the grate in Bailie's experimental unit, which had no inert removal capability, occurred quite predictably due to build-up of glass and "sticky" metal. This clogging was, no doubt, accentuated in the experimental unit by the fact that the grate was maintained at a temperature above the melting point of some steels. This hot grate was the result of a hot gas flow to heat the reactor (rather than a hot sand flow) and should not occur in an operational plant. Without the hot grate there may not be clogging from steel, but the 800°C (1500°F) sand temperature in the pyrolysis reactor can certainly be expected to cause problems from melting glass and aluminum. Thus, design of the "sand cleanup" unit on the schematic diagram (Figure 3-57) may be quite difficult, and certainly will be tied to the degree of preprocessing given the MMR prior to pyrolysis. The Stanford Research Institute study (ref. 3-68) recommended shredding the MMR to 2.5 centimeter (1 inch) maximum particle size, then using air classification. They estimated that the air classifier could be adjusted such that the lighter fraction would contain all the organics and about 25 percent of the inorganics. This lighter fraction, which would then be pyrolyzed, would contain about 8 percent inert material, largely glass. Although this is much better than the 26 percent inert content which might be typical of MMR (or the 40 percent reported by Bailie in his tests), the potential problems with this glassy inert material in the reactors can hardly be ignored.

Table 3-34 gives an analysis of the dried pyrolysis gas from the WVU process. The absence of nitrogen as a dilutant and the significant content of hydrocarbons give the gas a reasonably good heating value of about 1.65×10^7 joules/meter^3 (440 Btu/SCF). This gas should be quite valuable to many markets such as utility boilers provided transportation distances are relatively small. The gas could be upgraded to pipeline quality by a water-shift reaction, carbon dioxide removal, and methanation, if justified by transportation costs or by unwillingness of potential customers to install special burners for direct use of the moderate heating value gas.

From the numbers in Table 3-34 one finds that the predicted energy recovery of the WVU process is about 9.6×10^9 joules/metric ton (8×10^6 Btu/ton) for dry MMR. Assuming on energy content of 11.6×10^9 joule/metric ton (10×10^6 Btu/ton) of refuse, the thermal efficiency is very high. If the refuse moisture content is 25 percent, a thermal efficiency greater than 60 percent is obtained in the process. In addition to this substantial energy recovery some recovery of materials could easily be added to the system. Since

TABLE 3-33 (A)
ECONOMIC DATA-GARRETT PYROLYSIS PROCESS
PROCESS COST SHEET

PROCESS NAME: Garrett
DATA SOURCE: Schulz report, ref. 3-21
CAPACITY IN TONS/DAY: 1814 metric tons (2000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities		
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	$28,000,000	
OPERATING COSTS ($ PER YR)		
Maint. Material		
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead		
Utilities		
Taxes		
Insurance		
Interest		
Disposal of Residue	$ 553,000	
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	$ 7,420,000	
CREDITS ASSUMED ($ PER YR)	$ 3,108,000	

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid	$2,450,000	Oil at $0.10/liter (Oil @ $15.35/bbl or 3.50 x 2000 x 350)
Gas		
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals	462,000	High purity metals $11/metric ton ($10/ton or .66 x 2000 x 350)
Nonmagnetic Metals		
Glass	196,000	Glass at $5.51/metric ton ($5/ton or 28 x 2000 x 350)
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	$3,108,000	

TABLE 3-33 (B)
PROCESS COST SHEET

PROCESS NAME: Garrett
DATA SOURCE: MRI Report, ref. 3-2
CAPACITY IN TONS/DAY: 227 metric tons (250 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities		
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	$4,200,000	
OPERATING COSTS ($ PER YR)		
Maint. Material		
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead		
Utilities		
Taxes		
Insurance		
Interest		
Disposal of Residue		
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	$ 657,000	
CREDITS ASSUMED ($ PER YR)	$ 404,250	

CREDITS	DOLLARS/YR.	COMMENT
Fuel:		
Liquid	$ 306,000	
Gas		
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals	50,250	
Nonmagnetic Metals		
Glass	48,000	
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	$ 404,250	

TABLE 3-33 (B) (CONTINUED)
PROCESS COST SHEET

PROCESS NAME: Garrett
DATA SOURCE: MRI Report, ref. 3-2
CAPACITY IN TONS/DAY: 453 metric tons (500 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities		
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	$7,200,000	
OPERATING COSTS ($ PER YR)		
Maint. Material		
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead		
Utilities		
Taxes		
Insurance		
Interest		
Disposal of Residue		
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	$1,444,500	
CREDITS ASSUMED ($ PER YR)	$ 808,500	

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid	$ 612,000	
Gas		
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals	100,500	
Nonmagnetic Metals		
Glass	96,000	
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	$ 808,500	

TABLE 3-33 (B) (CONTINUED)
PROCESS COST SHEET

PROCESS NAME: Garrett
DATA SOURCE:
CAPACITY IN TONS/DAY: 907 metric tons (1000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities		
Building & Roads	$12,300,000	
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL	$12,300,000	
OPERATING COSTS ($ PER YR)		
Maint. Material		
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead		
Utilities	$ 3,888,000	
Taxes		
Insurance		
Interest		
Disposal of Residue		
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	$ 3,888,000	
CREDITS ASSUMED ($ PER YR)	$ 1,617,000	

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid	$1,224,000	
Gas		
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals	201,000	
Nonmagnetic Metals		
Glass	192,000	
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	$1,617,000	

TABLE 3-33 (B) (CONTINUED)
PROCESS COST SHEET

PROCESS NAME: Garrett
DATA SOURCE: MRI Report, ref. 3-2
CAPACITY IN TONS/DAY: 1814 metric tons (2000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $) Land Preprocessing Eqmt Processing Eqmt Postprocessing Eqmt Utilities Building & Roads Site Preparation Engr. & R & D Plant Startup Working Capital Misc.:	$21,200,000	
TOTAL	$21,200,000	
OPERATING COSTS ($ PER YR) Maint. Material Maint. Labor Dir. Labor Dir. Materials Overhead Utilities Taxes Insurance Interest Disposal of Residue Payroll Benefits Fuel Misc.:	$ 3,342,000	Based on 24 hour per day and 300 day per year operation.
TOTAL	$ 3,342,000	
CREDITS ASSUMED ($ PER YR)	$ 3,342,000	

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid		
Gas	$2,448,000	
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals	402,000	
Nonmagnetic Metals		
Glass	384,000	
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	$3,234,000	

TABLE 3-33 (c)
PROCESS COST SHEET

PROCESS NAME: Garrett
DATA SOURCE: Mallan & Finney (Ref. 3-51
CAPACITY IN TONS/DAY: 1814 metric tons (2000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land		Land not estimated
Preprocessing Eqmt)		
Processing Eqmt)	$14,000,000	
Postprocessing Eqmt)		
Utilities		
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:	400,000	
TOTAL	$14,400,000	
OPERATING COSTS ($ PER YR)		
Maint. Material)		
Maint. Labor)		
Dir. Labor)		
Dir. Materials)	$ 2,704,780	
Overhead)		
Utilities)		
Taxes)		
Insurance)		
Interest		
Disposal of Residue	84,000	This no. will be $168,000 unless a satisfactory method of reclaiming non-ferrous metal is developed.
Payroll Benefits		
Fuel		
Misc.:		Auxiliary fuel generated by pyrolysis process.
TOTAL	$ 2,788,780	

CREDITS ASSUMED ($ PER YR) $ 4,004,000

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid	$ 2,450,000	Highly viscous oil-may be some problem in finding market.
Gas		
Solid	161,000	
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals	931,000	
Nonmagnetic Metals		
Glass	546,000	
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	$ 4,004,000	

TABLE 3-34
COMPOSITION OF DRY PYROLYSIS GAS FROM THE WEST VIRGINIA UNIVERSITY PROCESS

	(By Volume)
CO	27.1%
CO_2	14.7
H_2	41.7
CH_4	7.7
C_2 unsaturates	7.1
C_2H_6	0.7
C_3 unsaturates	0.6
C_3H_8	0.4
Total	100.0%

Gross heating value 1.65×10^7 J/SCM (443 Btu/SCF)

Yield of gas per unit of dried refuse 0.58 SCM/kg (9.3 SCF/lb)

shredding is required for the process, little expense would be incurred by adding magnetic separation to recover most of the ferrous metals. The desirability of adding units to recover glass and/or aluminum from the heavy fraction resulting from the air classifier would depend greatly on market prices for the recovered materials.

3.4.4.4.2 Economic Data

Several independent economic evaluations of the fluidized bed have been made, but the results of the Stanford report (ref. 3-68) will be the only one presented. The WVU process is only a small experimental setup, and scaling up from laboratory size to a 907 metric ton/day (1000 ton/day) commercial plant involves considerable economic uncertainties. Additional economic data may be found in ref. 3-67.

Cost figures for both the two reactor and single reactor systems are summarized in Table 3-35 and represent costs and credits for construction and operation of a 907 metric ton/day (1000 ton/day) facility. As noted, the single reactor system has a higher initial capital cost, primarily due to pre and post processing equipment. It also produces a lower quality gas, making it less desirable.

Assumptions included in the study:

Plant life	20 years
Interest rate	6%
Construction period	2 years
Credit for refuse	\$4.40/metric ton (\$4.00/ton)

3.4.5 SUMMARY OF PYROLYSIS ALTERNATIVES

Because of the relative newness of the field of refuse pyrolysis it is very difficult to make definitive statements regarding the desirability of various systems. In particular, there is the possibility that some process which is now at the conceptual or experimental stage may become, in the future clearly preferable to the systems which have presently been demonstrated. On the other hand, some process which appears to be very promising at the conceptual or experimental stage may become technically or economically infeasible when construction of a commercial plant is attempted. Since at least five commercial plants for pyrolysis of MMR are currently under construction it can be expected that some of the data necessary for informed decision making will become available within the next few years. These five plants, though, only represent four types of processes, whereas Table 3-24, for example, contains sixteen possible (but not necessarily feasible) combinations of reactor types of heating conditions, with example processes listed for nine of these combinations. Thus, there are many types of processes which may be feasible, but for which operating data may not be available for some time.

Anyone faced with making an immediate choice of a pyrolysis process for some commercial application would surely be very interested in data from successful pilot plant operations. Table 3-23 shows at a glance that the largest scale pilot operations have been limited to two types of processes: vertical shaft and rotary kiln, both with direct heating. More limited scale pilot plants have demonstrated vertical and horizontal shafts with indirect heating and a fluidized bed. Obviously the data from the larger scale pilot plants can be extrapolated more reliably to commercial plant operation.

Aside from the basic problem of predicting the results of operation of various types of commercial plants, one will be most interest in the relative economics of the various alternatives. These economics will depend greatly on the local markets for various fuels and/or reclaimed materials, as well as on the processes considered.

TABLE 3-35 (A)
ECONOMIC DATA-WEST VIRGINIA UNIVERSITY PROCESS
PROCESS COST SHEET

PROCESS NAME: Fluidized Bed - West Virginia (2 reactor)
DATA SOURCE: Stanford Research Institute Report, ref. 3-68
CAPACITY IN TONS/DAY: 907 metric tons (1000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land	$ 100,000	
Preprocessing Eqmt	3,100,000	
Processing Eqmt	4,000,000	
Postprocessing Eqmt	1,600,000	
Utilities	1,400,000	
Building & Roads	500,000	
Site Preparation		
Engr. & R & D		
Plant Startup	500,000	
Working Capital	500,000	
Misc.:		
TOTAL	$11,700,000	
OPERATING COSTS ($ PER YR)		
Maint. Material	$ 290,000	
Maint. Labor)	990,000	
Dir. Labor)		
Dir. Materials		
Overhead		
Utilities	500,000	
Taxes)	200,000	
Insurance)		
Interest	960,000	
Disposal of Residue		
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	$ 2,940,000	
CREDITS ASSUMED ($ PER YR)	$ 1,227,648	

	DOLLARS/YR.	COMMENT
Fuel:		Based on 320 days.
Liquid		$0.47/10^9$ joules
Gas	$1,227,648	($0.50/10^6$ Btu)
Solid		
Power:		
Steam		5.2×10^5 SCM/day
Electricity		(18.4×10^6 SCF/day)
Hot Water		
Magnetic Metals		Heating value of
Nonmagnetic Metals		1.55×10^7 joule/SCM
Glass		(417 Btu/SCF)
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	$1,227,648	

TABLE 3-35 (B)
PROCESS COST SHEET

PROCESS NAME: Fluidized Bed - West Virginia (single reactor)
DATA SOURCE: Stanford Research Institute Report - ref. 3-68
CAPACITY IN TONS/DAY: 907 metric tons (1000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land	$ 100,000	
Preprocessing Eqmt	3,100,000	
Processing Eqmt	3,400,000	
Postprocessing Eqmt	3,000,000	
Utilities	1,400,000	
Building & Roads	500,000	
Site Preparation		
Engr. & R & D		
Plant Startup	500,000	
Working Capital	500,000	
Misc.:		
TOTAL	$12,500,000	
OPERATING COSTS ($ PER YR)		
Maint. Material	$ 290,000	
Maint. Labor	900,000	
Dir. Labor		
Dir. Materials		
Overhead		
Utilities	850,000	
Taxes	230,000	
Insurance	1,020,000	
Interest		
Disposal of Residue		
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	$ 3,290,000	
CREDITS ASSUMED ($ PER YR)	$ 1,790,000	

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid		
Gas	$ 611,500	Based on 320 days/yr $0.47/$10^9$ joules ($0.50/$10^6$ Btu)
Solid		
Power:		
Steam		
Electricity		7.73 x 10^5 SCM/day (27.3 x 10^6 SCF/day)
Hot Water		
Magnetic Metals		5.2 x 10^6 joule/SCM (140 Btu/SCF)
Nonmagnetic Metals		
Glass		
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)	$ 611,500	

The fuel product from the processes that have been tested in the four largest pilot plants (those greater than 31 metric tons (35 tons) per day) is a low heating value gas containing much nitrogen, since these processes use air for the oxidant in direct heating. It seems unlikely that it will ever be economical to transport this gas any significant distance, but it is usable in boilers located near the source. In the high temperature vertical shaft processes (URDC and Torrax) no preprocessing is required for the reactor, but it could be added if justified by markets for the byproducts. Since some preprocessing is required for the rotary kiln processes (Monsanto and Devco), some byproduct reclamation may be included at small additional cost. The Union Carbide process is basically similar to the other high temperature vertical shaft processes, but the use of pure oxygen as the oxidant improves the quality of the fuel gas. The quality of the raw Union Carbide gas could still not justify transportation very far, but it could be upgraded to methane by known chemical procedures if desired. Also, the very small amount of nitrogen in the Union Carbide gas minimizes one of the potential air pollution problems of the other direct heat processes. A disadvantage of the Union Carbide process is the hazard associated with separation and use of pure oxygen.

Processes using indirect heating also avoid the problems of nitrogen in the fuel gas (Kemp, Barber-Colman, Rust, WVU, A.D. Little). This lack of nitrogen along with the moderate temperatures used in these processes give fuel gases with improved heating value, as well as potential for methanation. The still lower temperature processes concentrate on production of liquid fuel (Garrett) or char (Georgia Tech). All of these processes require preprocessing of MMR, so are quite compatible with byproduct reclamation.

Again, it should be emphasized that the local markets for various forms of fuel and for various byproducts can be expected to be the controlling factors in economic comparisons.

3.4.6 A Study of a Proposed Pyrolysis Process

3.4.6.1 WHY IS ANOTHER PYROLYSIS PROCESS NEEDED?

With many pyrolysis techniques available, why should we search for more? The reason is that all pyrolysis processes in advanced stages of development have some drawbacks along with their merits. For example:

(a) The Union Carbide Purox Process (see section 3.4.4.1) has the merits of simplicity and the disposal of solid waste without any preprocessing. However, the equivalent of about one-third of the energy recovered by the process is needed to produce its oxygen requirement. Thus, from the standpoint of energy conservation, it is less attractive than some other processes Moreover, broad acceptance by municipalities may be doubtful due to the fear of the hazard from handling pure oxygen. Use of oxygen at high temperatures also eliminates the potential of recovering some valuable metals in the refuse.

(b) The Monsanto Landgard Process (see section 3.4.4.2) also has the merit of simplicity. However, its product is a low heating value gas 4.48×10^6 joule/SCM (120 Btu/SCF) which has limited applicability.

(c) The Occidental Petroleum Garrett Process (see section 3.4.4.3 and ref. 3-84) has the merit of producing a liquid fuel along with some gas with heating value up to 2.61×10^7 joule/SCM (700 Btu/SCF). Its drawbacks are:

1. very fine shredding is needed;
2. large quantities of char are produced; and
3. the liquid has high viscosity and acid content.

This latter product is a burden rather than a credit unless economical uses are found.

(d) West Virginia University Fluid Bed Process has the ability to produce a simple product gas of medium heating value 1.49-1.87×10^7 joule/SCM (400-500 Btu/SCF) without the use of pure oxygen. However, the capability of moving high density solid components into and out of the reactors is currently lacking. For this reason, extensive shredding and air classification are needed.

A pyrolysis process which can circumvent the drawbacks of other processes and which can be economically operated without adding much financial burden to municipalities is desirable.

3.4.6.2 DESCRIPTION OF THE NAAS PROCESS

After careful consideration of all aspects of the problem, with emphasis on maximizing energy recovery, a process referred to as the NAAS process is discussed in subsequent sections. Figure 3-64 is a schematic of the NAAS process.

The principal equipment of the process consists of two rotary kilns, one serving as a pyrolyzer and the other as a combustor. A continuous stream of dolomite circulates between them. The combustor is situated

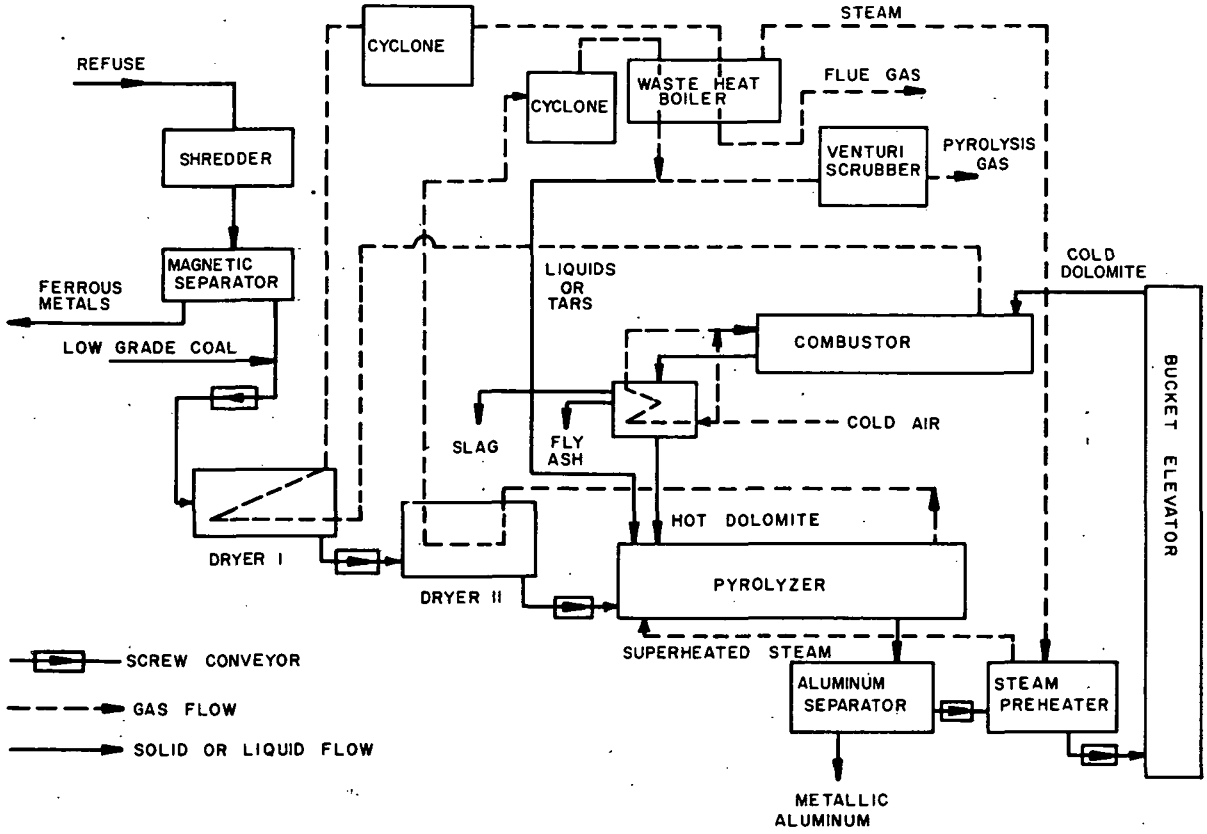


FIGURE 3-64
THE FLOW SHEET OF THE NAAS PROCESS

above the pyrolyzer and the dolomite moves from the former to the latter by means of gravity and screw conveyors. The circulation is completed by using a bucket elevator to return the dolomite to the combustor.

Two separators are inserted in the loop. One separates slag and fly ash from the burned dolomite, the other classifies metallic aluminum from a mixture of dolomite and char.

The front-end preparation installation consists of one shredder and one magnetic separator. The gas purification systems are conventional. The screw conveyors also serve as seals to keep flue gas separated from pyrolysis gas.

After rough shredding to 3 to 10 centimeters (1 to 4 inches) the Municipal Solid Waste (MSW) passes through a magnetic separator where ferrous metals are removed. The organics and the remaining inorganics are mixed with some low-grade pulverized coal by a screw conveyor. If the refuse contains very much moisture, two dryers will be needed. One dryer is heated by flue gas and the other by pyrolysis gas. The dried MSW is fed into the pyrolyzer by a screw conveyor where meets with hot dolomite -- at about 980°C (180°F) -- coming from the combustor. The direct contact between dolomite and organics produces a gas containing about 15 percent CO_2, 27 percent CO, 42 percent H_2, 8 percent CH_4, and 8 percent higher hydrocarbons. After pyrolysis, the residue char and carbon from the coal react with steam vapor to form water gas. The reaction heat is supplied by the heat generated by absorption of CO_2 by dolomite. The metallic aluminum is now in molten form and is separated from dolomite and char by a specially-designed separator. The remaining solid mixture is cooled down by using it to preheat low-pressure steam in a drum-type preheater. The solid mixture now is at about 372°C (700°F) and is moved into a bucket elevator which carries the dolomite and char mixture into the entrance of a combustor, where the char is completely burned by a preheated air stream.

The heat contents of flue gas and product gas leaving the dryers are recovered by a waste heat boiler where low-pressure steam is generated to satisfy the need of the water-gas reaction.

The heat contents of flue gas and product gas leaving the dryers are recovered by a waste heat boiler where low-pressure steam is generated to satisfy the need of the water-gas reaction.

The pyrolysis gas is further cooled down and purified in a Venturi scrubber and the flue gas is scrubbed by monoethanol amine for CO_2 purification.

The heat of combustion is transferred into the pyrolyzer in the forms of the sensible heat of dolomite and the heat of decomposition of $CaCO_3$ to CaO and CO_2. The dolomite, free from char, is fed into a specially-designed separator where slag and fly ash are separated from the dolomite stream, without taking it from the processing system. The separating medium is cold air. The preheated air from the separator is fed into a combustor or after burner. The main air is preheated by a preheater or by a two-rotary-tunnel system with the circulation of sands between them. A conventional tubular heat exchanger can also be used.

3.4.6.3 CONTROL OF OPERATION AND MAINTENANCE

The entire NAAS plant should be controlled by digital mini-computers in order to cope with the fluctuating nature of MSW feed rate and to minimize the need for municipalities to employ high caliber technical personnel.

All moving parts except blowers and water pumps are driven by D.C. current. The speeds of all D.C. motors are interrelated to each other such that the overall processing rate is kept uniform with the MSW feed rate to achieve complete gasifications and combustion. The processing rate can be varied from zero (if repairs are being made) up to maximum production capacity. The gas and air blowers are controlled by bypassing a part of the flows.

3.4.6.4 POSSIBILITY OF ALUMINUM RECOVERY

Metallic aluminum is the second most valuable resource in MSW. If it can be recovered with no additional cost or energy consumption, about 95% of the energy expended in producing virgin aluminum can be recovered indirectly.

In the NAAS process metallic aluminum is melted in the pyrolyzer where a reducing atmosphere is maintained. However, questions arise as to whether metallic aluminum at about 660°C (1220°F) can be oxidized by CO, CO_2, and water vapor. Thermodynamic calculations show that at room temperature and 760°C (1400°F) the equilibrium partial pressures of all three gases are negligible when they are in contact with metallic aluminum. Therefore, the feasibility of aluminum recovery depends on the rate of reaction. According to Van Horn (ref. 3-85) the rate of oxidation of aluminum is about 0.16 grams per square meter per hour at 760°C (1400°F). Moreover, with the addition of traces (0.001 percent) of beryllium, the oxidation can be totally stopped (ref. 3-86). Therefore, it is highly probable that the major part of the metallic aluminum in the MSW can be recovered. Whether the addition of this amount of beryllium will affect the usage of aluminum for making cans or other food containers should be studied.

3.4.6.5 ECONOMICS OF THE NAAS PROCESS

A hypothetical NAAS plant to handle 1,134 metric tons (1,250 tons) per day of raw (wet) MSW has been designed and the individual equipment sized. Equipment prices were estimated or obtained by telephone calls to manufacturers. The economic analyses, with assumptions given, for five operating conditions are shown in Table 3-36. The encouraging economics shown in this table are due to the following:

1. The quantity of salable gas is increased because of the gasification of the char produced together with the carbon in the coal fed into the system.
2. About 80 percent of the metallic aluminum present is recovered, which contributes to a considerable reduction of net operating costs.
3. Utility usage is low.

3.4.6.6 AN EXPECTED TECHNICAL PROBLEM AND A POSSIBLE SOLUTION

Entrainment of dolomite in the outgoing gas and solids streams is a possibility. The gas velocities of flue gas from the combustor and the product gas from the pyrolyzer are in the ranges of 0.8 to 1.1 meter/second (2.5 to 3.5 feet/second). The gas streams will carry some dolomite with them, but when the gases are cooled in the dryers the velocities are reduced to about 0.3 meter/second (1 foot/second). Some of the entrained dolomite will drop out at the lower velocity. Dolomite collected in the dryers is fed back to the pyrolyzer by screw conveyors. The entrained dolomite is further collected in the multicyclones. Some very fine sized dolomite will be carried through the waste heat

TABLE 3-36
ECONOMIC ANALYSIS OF THE NAAS PROCESS

A. DESIGNED CAPACITY: 1134 METRIC TON/DAY (1250 TON/DAY)

B. TOTAL INVESTMENT: $12,467,500 (BASED ON M & S INDEX OF 360)

C. ANNUAL GROSS PROFIT ASSUMPTIONS MADE:

PRODUCT GAS AT $0.71/10^9 joules ($0.75/million Btu)
ALUMINUM AT $331/METRIC TON ($300/TON)
PRICE OF 98% PURE CO_2 $8.82/METRIC TON ($8/TON)
CAPITAL COST AT 10% INTEREST RATE AND 20 YEARS LIFE
BREAKEVEN ON HANDLING OTHER PRODUCTS

Operating Condition	Gross Cost (Profit)	$/dry metric ton	$/dry ton
1. 100% capacity without CO_2 sale	($ 321,000)	+$1.00	+$0.90
2. 75% capacity without CO_2 sale	$ 528,900	-$1.76	-$1.60
3. 50% capacity without CO_2 sale	$1,335,300	-$4.47	-$4.05
4. 100% capacity with CO_2 sale	($1,256,680)	+$4.20	+$3.81
5. 50% capacity with CO_2 sale	$ 864,760	-$2.88	-$2.61

boiler and air preheater and will be collected in the scrubbers from which it can be recovered periodically.

If the dolomite carried out by slag and fly ash because of incomplete separation is higher than can be endured economically, it should be recovered by a hydraulic classifier.

3.4.6.7 MAIN FEATURES OF THE NAAS PROCESS

Assuming that the potential mechanical problems of the proposed process such as leakage from rotary kilns, movement of solids at elevated temperatures, and minimization of dolomite loss are solved, the NAAS process would be expected to do the following:

1. Recover metallic aluminum without extensive shredding and power consumption.

2. Produce a gas with a relatively high heating value -- about 1.85 x 10^7 joule/SCM (500 Btu/SCF) -- which can be used as a fuel for a power plant or a gas turbine. This comes about because of separation of combustion and pyrolysis and lowering the CO_2 content by absorption with dolomite.

3. Increase the quantity of product gas with consequent improvement of process economics. This results from using the heat of absorption of CO_2 from the pyrolysis gas by the dolomite to promote gasification of residue char and carbonized low-grade coal. The heat content of low-grade coal is thus converted to valuable clean energy.

4. Capital investment will not be excessive. No expensive air pollution control equipment is required.

5. Flue gas from the NAAS process will be sulfur-free, with very low sulfur content. This is because dolomite is a powerful sulfur removal agent. If recovered, sulfur may be sold to lower the net operating cost of the process.

3.4.6.8 POLITICAL, ENVIRONMENTAL, LEGAL, AND SOCIAL IMPLICATIONS OF THE NAAS PROCESS

When laws and regulations which provide incentives for recycling resources, such as equal treatment on transportation rates for recycled and virgin materials, are established, there would be moe potential markets for ferrous and nonferrous metals recovered from the NAAS process.

These materials would then have higher prices.

If all byproducts can be sold, which is a possibility, there would be no need for landfill. If there is no market for some of the products, they could be landfilled, without causing any land pollution problems. Air pollution would be minimal because both product gas and flue gas are scrubbed with water, removing particulate matter.

The use of a rotary kiln as a combustor permits good control of temperature with no local overheating expected. Therefore, the NO_x content of the flue gas should meet EPA regulations as do most other pyrolysis processes.

No difficulty with water pollution is expected because the scrubbing water is recycled and its salt content is recovered. The NAAS process involves no danger with hazardous materials and good acceptance by municipalities is expected if the process is available.

3.4.6.9 DECISION MAKING FOR CITY OFFICIALS IN RELATION TO THE NAAS PROCESS

If a city is in urgent need of solving a solid-waste disposal problem, it should not consider the NAAS process because this is, at present, only a conceptual design; no experimental verification has been done.

For long range planning, however, the NAAS process should be considered along with other alternatives, because it does appear to have merits not possessed by some of the other pyrolysis processes.

3.5 BIODEGRADATION PROCESSES

3.5.1 INTRODUCTION

Among the possible processes available for the reduction and/or conversion of MMR (mixed municipal refuse) are those which fall under the general heading of biodegradation. Biodegradation can be defined as the reduction of refuse by the use of organic methods. The organic methods are divided into two general categories. The first is the direct reduction of the refuse by biological organisms which includes aerobic and anaerobic conversion. The second is the reduction of the refuse by biochemical methods. This second is the reduction of the refuse by biochemical methods. This includes chemical preprocessing, and/or the use of enzymes. These enzymes are either the metabolic waste products or the selected extractions from specific species of protozoa or fungi. In anaerobic degradation processes, degradation takes place in an oxygen deficient environment. Biochemical conversion processes accomplish either refuse reduction or conversion of cellulose and in many applications both aspects are utilized.

Having defined biodegradation and listed the major biological conditions under which this type of refuse reduction occurs, the question of perspective and applicability must also be considered.

Biodegradation has been the normal mechanism for the removal of the solid wastes produced by living organisms since the beginning of the biosphere. During all but the smallest segment of man's evolution, he has been born, lived, died, and was buried among the waste products of his society. In hunting societies, the wastes are simply discarded at the point of origin. In agricultural societies, they are placed in the adjacent fields. In man's early cities, he did essentially the same thing, producing the city mounds found in the Middle East. This method was used throughout the middle ages in Europe. It was only with the advent of paved streets in Europe that there was some fixed surface to clean down to. The banishing of swine from the city streets at about the same time removed the scavengers which consumed the waste. Thus street sweepers and refuse collectors started at about the same time.

Along with the industrial age came a change in the composition of the refuse. Previously, because of cost and economic level, the refuse was mainly garbage, offal, and manure. With increasing technology, cellulose in the form of paper and clothing began to appear in the refuse. With increasing industrialization, glass and finally metal also appeared in appreciable amounts, along with increasing amounts of cellulose. These later changes have been mainly within the twentieth century. However, man still views MMR as the type of refuse found in a pre-industrial world which means that biodegradation is usually the process that comes to mind as the best metho of solid waste disposal.

Biodegradation is the process that produces the least negative impact on the biosphere. However, MMR with its present composition and daily production, puts definite limitations on the regions where biological processes can be used to convert solid waste into energy. The limiting aspects of different biodegradation processes as well as the advantages will become more explicit as the different categories of biological reduction are discussed.

3.5.2 COMPOSTING

The earliest methods of organic solid waste conversion were in the general category of rotting. Where the conditions were proper, this decay would produce a humus as an end product. This process is known as composting and is a biological degradation of organic materials. Since this report is considering energy recovery from MMR, the emphasis in this chapter will be on the composting of residential and industrial waste found in MMR. It might be noted that properly designed, built, and managed composting systems will also process raw or partially digested sewage sludge into pathologically safe humus products.

Let us now consider the small compost pile in some detail. The most important aspect for the success of any composting system is the proper decomposition of the organic waste which is induced by numerous microorganisms. These include various types of bacteria, fungi, actinomycetes, and protozoa. The small compost pile, where the surroundings are in a normal ecological state, will have animals that speed up the physical decay. Examples of these small invertebrates are mites, millipedes, insects, and earthworms. In larger commercial processes, these minute pests will usually be missing since the volume of the compost is large compared to its interface surface with an ecologically balanced surrounding environment.

The compost pile is exactly what its name implies. It can be placed in a heap, a pit, or any other shape. The optimum pile dimensions are 0.91 meters (3 feet) to 1.52 meters (5 feet) high and may vary from 0.91 meters (3 feet) to 3.04 meters (10 feet) wide. These piles may be any length desired. When the length is greater than the width, the compost pile is called a windrow. The organic fraction of the MMR or the waste is the major energy source consumed by the decomposer organisms. The organic materials most easily composted include: garbage, leaves, grass clippings, sawdust, manure, organic meal, dried blood, and organic sludge. It should be noted, Zanoni (ref. 3-87) that these constitute the majority of rubbish and food waste components in typical MMR. Generally a pH range from 6 to 8 is required for optimum microbial decomposition rates and humus quality, especailly for aerobic composting. An anaerobic composting system is also possible but the pH values are slightly lower (higher acidity). Anaerobic decomposition as a process will not be discussed with respect to specific composting systems but will be discussed in the section on methane production.

Since the decomposer organisms are microorganisms, the moisture requirements are fairly stringent. These microorganisms require a constant high moisture environment generally between 50 and 70 percent, without submersion. If the water percentage is too great, there will be insufficient air in the spaces between pieces of the refuse. Under these conditions, the aerobic microorganisms will either die or transform themselves into a dormant state in order to survive the lack of oxygen. Also, if the moisture levels are too large, nutrients are lost in the leachate and anaerobic microorganisms will begin to replace the aerobic microorganisms. The degree of replacement accelerates with increasing moisture content. On the other hand, if the compost becomes too dry, the decomposition process will first slow down with increasing dryness and at some moisture percentage cease completely. Other factors important to the rate of decomposition are ambient climatic conditions, size of compost pile and composition of refuse. The climatic effects are inversely proportional to the size and mass of the composting volume and the amount of protection provided.

The question of the need for inoculums to start the composting process has been debated for many years. Folk wisdom and earlier work implied that the use of a starter would accelerate the process and produce better humus. Typical inoculums were animal manure, special bacteria cultures, or soil. Golueke, Card, and McGauhey (ref. 3-88) conducted a critical evaluation of the effects of inoculum use in the composting process. Using the typical inoculums, the research showed that for identical composting systems, the commencement time for active degradation, temperature rise times and stability, and required time to produce humus was essentially identical for all inoculated and control systems.

Two major conclusions can be drawn from this research. One, the time needed to compost MMR is independent of bacterial enrichment. Thus, no injections of microorganisms are required. Two, by use of other materials in MMR, either during composting or afterwards, the composition and fertilization values of the humus can be varied within certain limits. These two conclusions taken together imply that one can combine MMR with other organic wastes and still produce pathologically acceptable humus or compost. The types of organic waste that can be added to MMR include animal manure, offal, sewage sludge, and industrial grade biological wastes.

When the aerobic decomposition processes begin to occur, the microorganisms release fairly large amounts of energy in the form of heat. Because of the insulative properties of the MMR or refuse, the volume of the composting material begins to warm up. Very little heat is lost from the compost pile by either convection or conduction, the major heat losses, except at the surface, are by radiation. This rise in temperature means that the composting process is progressing properly. The temperature rise also provides empirical evidence that the carbon to nitrogen ratio is within the proper range of values and signifies the rapid growth and multiplication of the microorganism population.

In some specialized composting systems, the temperature rise takes less than 24 hours, but 48 hours would be more typical. As the temperature rises to 45°C (112°F) the population levels of thermophilic microorganisms rise rapidly. These thermophilic, or heat loving microorganisms, multiply rapidly while the mesophilic forms die off. The thermophilic bacteria, fungi, and actinomycetes thus become the major decomposer organisms. In a temperature range of 45°C (112°F) to 65°C (150°F), the population of thermophilic microorganisms may be more than 10^{12} microorganisms per kilogram of the organic fraction of the refuse. Since the temperature pattern is essentially the measure of the efficiency of the aerobic thermophilic decomposer organisms, it is used to determine the state of the decomposition process.

If the composting material is raised to 65°C (150°F) and held there for a sufficient length of time, the germs and parasitic microbes will be destroyed. The obvious problem is that the surface of the compost will have the temperature of the ambient surroundings. Since the temperature profile must be continuous in the compost, there will be material in the surface region which will not reach 65°C (150°F) in a static compost process. Thus, one must redistribute the material, placing the outer surface layer in the center.

The composting process is complete and the resulting compost or humus material is ready for use when the temperature within the pile returns to the ambient value. When this happens, the humus will have three main characteristics. One, it will be finely divided and crumbly if the input refuse was ground. Two, it will be dark in color. Three, the carbon to nitrogen ratio will range from a low value of 10 to 1 to a high value of 20 to 1.

This section has discussed the composting process with respect to an already existing prototype operation which is known as the compost pile. When commercial composting operations are considered, the biophysics of the organic microorganism part of the individual process will always be the same as the simple compost pile. The mechanical systems will serve only two purposes - one to speed up the process and two, to improve the quality of the resulting product. Obviously, these two purposes must be balanced in some manner in order to maximize the tons/day processed and accelerate decomposition time. The proper balance of quantity and quality will determine the total volume of composting material which must be involved in the decomposition process from start to finish, i.e., from MMR input to humus output.

3.5.2.1 COMPOSTING PROCESSES

In order to discuss some of the composting processes, the basic characteristics of the input material must be discussed first. Namely, what is the composition of the feed, here MMR, which is uniquely pertinent to biological methods? This will be followed by a discussion of the basic composting processes. Third, an economic analysis of certain specific United States based composting operations will be considered. The closing section will discuss the specific problems of composting and suggestions for further study.

Solid Waste and Preprocessing

Before considering any biodegradation process as the possible solution for a waste product, the composition of this waste product must be analyzed. The organic composition analysis must consider both the quantity and quality of the MMR. Not only must there be a significant percentage of organic material in the MMR, but the nutritional value which includes carbohydrates, fats, and proteins must be adequate. Also, if the carbon to nitrogen ratio is not within the proper range of values, the rate of biological decomposition will be reduced.

An analysis of published MMR composition, previously tabulated in Table 3-3 and many other references is not the total refuse story. The percentage of specific components vary not only with geographic location, but also with season and economic level. As Wiley and Kochtitzky note (ref. 3-89) the increases in the per capita volume of MMR produced are much greater than the increase in weight, which means that the MMR is becoming more bulky and less dense. The greatest increase in MMR production has been in the area of low density organic combustibles. The increase is primarily in the form of paper and plastics. This increase is coupled with a reduction in the volume of garbage and trash. In other words the calorific value of MMR has increased continually, but this has been coupled with a decrease in the nutrient content. The decreasing microorganistic nutritional value has two distinct effects on the composting process. One, the composting operation will take longer to complete with respect to breaking down the cellulose. And two, the humus produced will be of lower quality.

The quality of the compost produced depends directly on the amount of preprocessing and/or post processing done to the MMR. The attempted composting of raw MMR would lead to a product which could be called semi-rotted refuse. The obvious problems due to constituents such as bulk, non-organics, and containers would lead to an incomplete decomposition. Thus the MMR needs to be shredded first for uniform and reproducible composting.

The ideal preprocessing system for composting would remove all glass, ferrous metal, aluminum, non-ferrous metal, plastics, leather, and rubber. Even though the plastics, leather, and rubber are technically organic, they effectively resist degradation long enough to insure they will come through the composting process time with little disintegration. The remaining material should be shredded so that it passes through a 2.54 centimeter (1 inch) mesh screen.

In actual fact, the shredded MMR will contain at least plastics, leather, and rubber. Also the shredded and separated MMR usually will still contain small amounts of metal and glass. The amount of the metal and glass remaining is inversely proportional to the fineness of shredding and the complexity or completeness of the separation system. Most shredding processes produce enough heat to dry the MMR. But, since the composting process requires a moisture level of 50 to 70 percent, the wet separation techniques can be used on MMR being prepared for biological decomposition. Because of the fact that some percentage of the non-decomposable materials, such as plastic, remain in the preprocessed MMR, the optimum shredding size is reduced. In fact the larger the percentage of plastic, glass, and metal the separation system passes through, the smaller the shredding size should be.

The quality of the humus produced by composting is inversely proportional to the quantity of plastics, rubber, and leather included. Humus with appreciable amounts of any of these undesirable products has fewer uses and thus smaller markets.

3.5.2.2 REVIEW OF THE MAJOR COMPOSTING PROCESSES

A complete survey of the different composting processes used in the various countries of the world indicate there are approximately 30 composting systems which are identified by either the names of the inventors or by some proprietary name.

Table 3-37 lists the more typical composting processes. The 16 processes listed in the table cover the major characteristics of all 30 processes, and are from Breidenbach (ref. 3-90). Each system consists of a preprocessing and/or postprocessing system coupled with a digester. The digester may consist of either windrows, pits, trenches, cells, tanks, multistoried or multidecked towers or buildings, drums, or bins. Some processes combine more than one of these digester types. The usual combination is a special digester combined with storage area for curing which usually takes place in either a windrow or bin. The basic differences between the 16 typical processes are given in Table 3-37. Rather than discussing each process separately, the basic characteristics of all municipal composting systems will be considered. The operation of a modern composting plant can be broken down into five sequential steps. These steps are: preparation, digestion, curing, finishing or upgrading, and storing.

The preparation or preprocessing consists of receiving, sorting, separation, grinding, and adding sewage sludge. The actual aspects, the possible ordering of the preprocessing and the types of equipment used are discussed elsewhere in this report. Here we will only state the required size, moisture, and carbon to nitrogen ratio which, in general, the organic fraction of the MMR should have when it enters the digestion stage.

Since the moisture content of ground refuse must be maintained within a specific range for proper digestion, raw or digested sewage can be added to provide the extra moisture. However, the incoming refuse has different moisture values depending upon seasonal variations in composition and daily weather conditions. This means that with respect to moisture content, the amount of sewage sludge added will vary from day to day. Figure 3-65 shows what

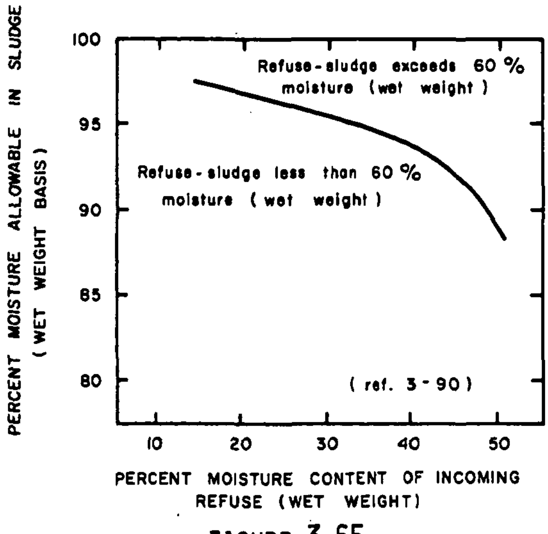


FIGURE 3-65
VARIATION IN REFUSE/SLUDGE MOISTURE CONTENT

TABLE 3-37
TYPICAL COMPOSTING PROCESSES

Process Name	General Description	Location
1. Bangalore (Indore)	Trench in ground, .6m to 1m (2 to 3 ft.) deep. Material placed in alternate layers of refuse, night soil, earth, straw, etc. No grinding. Turned by hand as often as possible. Detention time of 120 to 180 days.	Common in India
2. Caspari (briquetting)	Ground material is compressed into blocks and stacked for 30 to 40 days. Aeration by natural diffusion and air flow through stacks. Curing follows initial composting. Blocks are later ground.	Schweinfurt, Germany
3. Dano Biostabilizer	Rotating drum, slightly inclined from the horizontal, 2.7m to 3.7m (9 ft. to 12 ft.) in diameter, up to 45.7m (150 ft.) long. One to 5 days digestion followed by windrowing. No grinding. Forced aeration into drum.	Predominately in Europe
4. Earp-Thomas	Silo type with 8 decks stacked vertically. Ground refuse is moved downward from deck to deck by ploughs. Air passes upward through the silo. Uses a patented inoculum. Digestion (2 to 3 days) followed by windrowing.	Heidelberg, Germany; Turgi, Switzerland; Verona and Palermo, Italy; Thessaloniki, Greece
5. Fairfield-Hardy	Circular tank. Vertical screws, mounted on two rotating radial arms, keep ground material agitated. Forced aeration through tank bottom and holes in screws. Detention time of 5 days.	Altoona, Pennsylvania, and San Juan, Puerto Rico
6. Fermascreen	Hexagonal drum, three sides of which are screens. Refuse is ground. Batch loaded. Screens are sealed for initial composting. Aeration occurs when drum is rotated with screens open. Detention time of 4 days.	Epsom, England
7. Frazer-Eweson	Ground refuse placed in vertical bin having 4 or 5 perforated decks and special arms to force composting material through perforations. Air is forced through bin. Detention time of 4 to 5 days.	None in operation
8. Jersey (also known as the John Thompson system)	Structure with 6 floors, each equipped to dump ground refuse onto the next lower floor. Aeration effected by dropping from floor to floor. Dentention time of 6 days.	Jersey, Channel Islands, Great Britain, and Bangkok, Thailand
9. Metrowaste	Open tanks, 6m (20ft) wide, 3m (10 ft) deep, 61m (200ft) to 122m (400 ft) long. Refuse ground. Equipped to give one or two turnings during digestion period (7days). Air is forced through perforations in bottom of tank.	Houston, Texas and Gainesville, Florida

TABLE 3-37 (CONTINUED)

Process Name	General Description	Location
10. Naturizer or International	Five 2.7m (9 ft) wide steel conveyor belts arranged to pass material from belt to belt. Each belt is an insulated cell. Air passes upward through digester. Detention time of 5 days.	St. Petersburg, Florida
11. Riker	Four-story bins with clam-shell floors. Ground refuse is dropped from floor to floor. Forced air aeration. Detention time of 20 to 28 days.	None in operation
12. T. A. Crane	Two cells consisting of three horizontal decks. Horizontal ribbon screws extending the length of each deck recirculate ground refuse from deck to deck. Air is introduced in bottom of cells. Composting followed by curing in a bin.	Kobe, Japan
13. Tollemache	Similar to the Metrowaste digesters.	Spain; Southern Rhodesia
14. Triga	Towers or silos called "Hygienisators". In sets of 4 towers. Refuse is ground. Forced air aeration. Detention time of 4 days.	Dinard, Plaisir, and Versailles, France; Moscow, U.S.S.R.; Buenos Aires, Argentina
15. Windrowing (Normal, aerobic process)	Open windrows, with a "haystack" cross-section. Refuse is ground. Aeration by turning windrows. Detention time depends upon number of turnings and other factors.	Mobile, Alabama; Boulder, Colorado; Johnson City, Tennessee; Europe; Israel; and elsewhere
16. van Maanen process	Unground refuse in open piles, 120 to 180 days. Turned once by grab crane for aeration.	Wijster and Mierlo, the Netherlands

SOURCE: Breidenbach, ref. 3-90.

happens when MMR is not uniform with respect to water content. The figure shows the percent of moisture allowable in the sludge for the same population base for both MMR and sewage production. Let us consider another aspect of the sewage sludge problem. If the sludge is not dewatered, and one wants to maintain a 60 percent water content in the sewage sludge and refuse mixture, then all the sewage sludge produced will not be usable for composting. The quantitative aspects of this analysis are shown in Figure 3-66. The only solution to this dilema is to either have a complete separate sewage treatment plant or provide facilities for partially dewatering the sewage sludge.

The second stage of the process is the digestion or decomposition phase. This is carried out either in open windrows or enclosures. In most modern composting plants, the aerobic process is used rather than the anaerobic. There are three major reasons for this: time of process, temperature, and order problems. The aerobic decomposition microorganisms require free oxygen to decompose the waste. The speed of decomposition is oxygen dependent. Too little oxygen and the process may either slow down or go anaerobic. Thus, in the forced digestion systems, oxygen must be introduced by forced draft or agitation. Windrow systems get oxygen by turning. The forced digestion system reduces the windrow composting time of approximately six weeks to around five to seven days. In the aerobic systems, the temperature reaches 60°C (140°F) to 70°C (160°F) or higher. This level of heat in

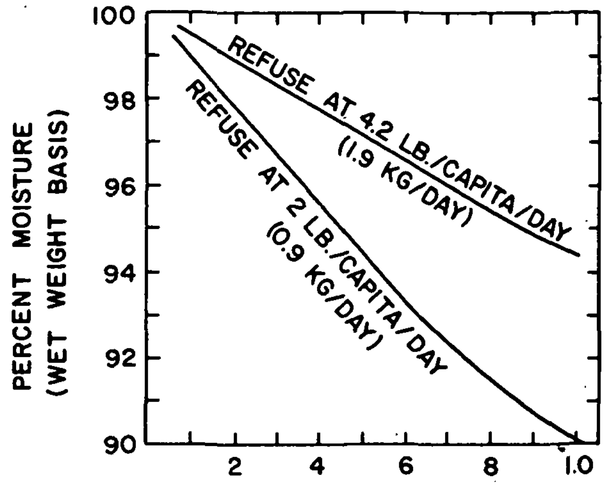


FIGURE 3-66
USABLE SEWAGE SLUDGE AS A
FUNCTION OF MOISTURE

the processing and finishing (Figure 3-67, from ref. 3-90) destroys the pathogenic organisms, weed seeds, fly ova, etc.

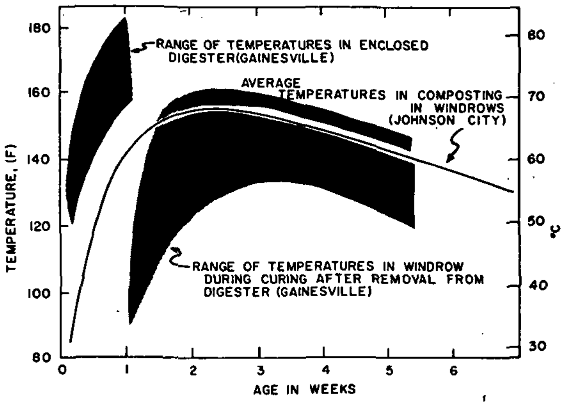


FIGURE 3-67
TYPICAL AND COMPARATIVE
TEMPERATURE PROFILES OBTAINED FROM
COMPOSTING MUNICIPAL REFUSE

This should be compared with the anaerobic system, where temperatures are only about 38°C (100°F) to 55°C (130°F) which means pathogens may survive. Also anaerobic decomposition produces foul odors. In aerobic decomposition, decomposition progresses rapidly without excessively unpleasant odors. The major odor and pest problems in the windrow method are from either cooler outer regions or pockets of the windrow where the oxygen has been exhausted and anaerobic decomposition is taking place.

With all the variables, proper moisture, particle size, and sufficient oxygen being maintained at constant proper values, the time required for digestion will depend on the initial carbon to nitrogen ratio. This is most critical for the processes which use a short active decomposition time.

Figure 3-68 shows the length of time needed for composting as a function of the initial C/N ratio. The dotted line serves

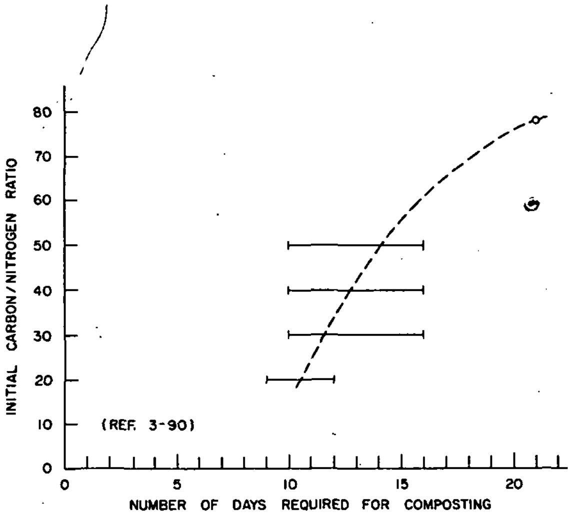


FIGURE 3-68
COMPOSTING TIME VS
INITIAL C/N RATIO

only to show the trend. Studies have shown that under optimum conditions, with an initial C/N ratio of 30 to 35, active decomposition processes produce humus in 2 to 5 days. The high C/N ratios are due to the large amounts of carbon in MMR which are not readily available since they are in the form of cellulose and lignin. Reference 3-91 contains additional information on C/N ratios and the effects on anerobic decomposition.

The pH of MMR turns out to be unimportant as an actual process control. However, the pH values are good indicators of the process parameters and the type of decomposition microorganisms present. To illustrate this, let us consider a specific example, namely the Johnson City windrow process. The pH vs compost age curve for the Johnson City windrow process is shown in Figure 3-69. The initial pH of refuse at Johnson City is usually between 5 and 7. Since the refuse is, on the average, at least three days old when it arrives at the plant, the initial pH drops. This is

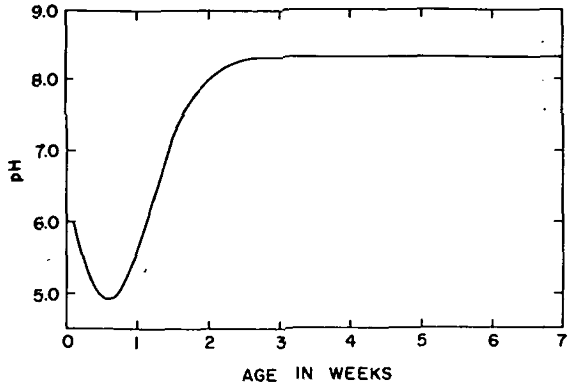


FIGURE 3-69
PH VS. COMPOST AGE CURVE FOR
JOHNSON CITY WINDROW PROCESS

because of the conditions under which the MMR is stored before collection. Garbage containers and piles are fairly air tight, thus acid forming anaerobic decay has started. The first step of this process is for the acid producing microorganisms to turn the material acidic. If the systems went completely acid anaerobic, the pH could drop to around 4.5. At the end of one or two days when the aerobic microorganisms have taken over the decomposition process, the pH goes up to 8 and stays at this value throughout the composting process.

The time of curing depends on how the humus is to be used. At the end of the curing process the temperature has dropped to the ambient level and the moisture level has fallen by evaporative drying. Thus curing depends on three things: the state of the compost on leaving the digester or decomposer state; the method used; and the final use for the humus.

Finishing of the humus depends upon the process used to produce it and the ultimate use of the compost. Thus finishing can consist of screening to remove glass, metal, or plastic; grinding to reduce size, pelletizing or blending; and/or enrichment.

An example of the elemental composition of finished humus is given in Table 3-38. This particular table is for 42 day old compost from the Johnson City windrowing process. Cured compost from any of the aerobic processes would have comparable percentages. The important fact to note is the insignificant change in the final composition of the compost due to the addition of sewage sludge before the decomposer or digestion stage.

The previous discussion of the general composting process is applicable to all the aerobic composting processes listed in Table 3-37. However, even though the process seems fairly simple and straightforward, the history of composting in the United States has been anything but a success. A number of municipalities that have tried the composting method of energy and resource recovery are listed in Table 3-39. It is immediately noted that all but two of the MMR composting plants in the United States are closed. It would seem that there is obviously something wrong with composting as practiced in this country, even though composting offers some advantages where it is used to solve specific problems or fit certain circumstances.

The Fairfield-Hardy composting process is used in Altoona, Pennsylvania, and it is the longest continuously operating composting plant in the United States. The economics of this plant and process are fairly representative for all accelerated decomposition systems and will be discussed in detail in the next section.

3.5.2.3 FAIRFIELD-HARDY

The Fairfield Engineering Company developed and applied the Fairfield-Hardy composting system to the refuse problem of Altoona, Pennsylvania. This plant, which has been operating for many years, processes approximately 23 metric tons (25 tons) of separated refuse per day with a maximum capacity of 41 metric ton/day (45 ton/day). The waste material processed by the plant includes a portion of the garbage collected by the city. Altoona is unique in the fact that it still has separate garbage and refuse collection. It should be noted that a mechanical composting plant for a city with a population of 200,000 would require 3.24×10^4 - 4.05×10^4 square meters (8-10 acres) while a comparable windrow plant would require at least 2.42×10^5 square meters (60 acres).

Figure 3-70 shows a schematic of the Altoona plant. Since garbage and rubbish are collected separately, no initial hand sorting is required. This means that the delivered separated MMR is fed directly into a Williams hammermill. After this initial grinding, secondary grinding is performed in a hydropulper. Sewage sludge solids are added to the hydropulper to enrich the MMR and to increase the water content for the decomposer in microorganisms. After the hydropulper, the now slurried ground refuse passes through a bar screen which is used to remove metal cans, plastics and other non-decomposable

TABLE 3-38
ELEMENTS IN 42-DAY-OLD COMPOST AT JOHNSON CITY*

Element	Percent dry weight (average) Containing sludge (3%-5%)	Without sludge	Range (all samples)
Carbon	33.07	32.89	26.23 - 37.53
Nitrogen	0.94	0.91	0.85 - 1.07
Potassium	0.28	0.33	0.25 - 0.40
Sodium	0.42	0.41	0.36 - 0.51
Calcium	1.41	1.91	0.75 - 3.11
Phosphorus	0.28	0.22	0.20 - 0.34
Magnesium	1.56	1.92	0.83 - 2.52
Iron	1.07	1.10	0.55 - 1.68
Aluminum	1.19	1.15	0.32 - 2.67
Copper	< 0.05	< 0.03	
Manganese	< 0.05	< 0.05	
Nickel	< 0.01	< 0.01	
Zinc	< 0.005	< 0.005	
Boron	< 0.0005	< 0.0005	
Mercury	not detected	not detected	
Lead	not detected	not detected	

*Ref. 3-90.

TABLE 3-39
MUNICIPAL SOLID WASTE COMPOSTING PLANTS IN THE UNITED STATES (1973)

Location	Company	Process	Capacity metric ton/day	Capacity ton/day	Type Waste	Began operating	Status
Altoona, Pennsylvania	Altoona FAM, Inc.	Fairfield-Hardy	41	45	Garbage, paper	1951	Operating
Boulder, Colorado	Harry Gorby	Windrow	91	100	Mixed refuse	1965	Closed (1971)
Gainesville, Florida	Gainesville Municipal Waste Conversion Authority	Metrowaste Conversion	136	150	Mixed refuse, digested sludge	1968	Closed (1971)
Houston, Texas	Metropolitan Waste Conversion Corp.	Metrowaste Conversion	327	360	Mixed refuse, raw sludge	1966	Closed (1970)
Houston, Texas	United Compost Services, Inc.	Snell	272	300	Mixed refuse	1966	Closed (1966)
Johnson City, Tennessee	Joint USPHS-TVA	Windrow	47	52	Mixed refuse, raw sludge	1967	Closed (1970)
Largo, Florida	Peninsular Organics, Inc.	Metrowaste Conversion	45	50	Mixed refuse, digested sludge	1963	Closed (1967)
Norman, Oklahoma	International Disposal Corp.	Naturizer	32	35	Mixed refuse	1959	Closed (1964)
Mobile, Alabama	City of Mobile	Windrow	272	300	Mixed refuse, digested sludge	1966	Closed (1971)

TABLE 3-39 (CONTINUED)

Location	Company	Process	Capacity metric ton/day	Capacity ton/day	Type Waste	Began operating	Status
New York, New York	Ecology, Inc.	Varro	136	150	Mixed refuse	1971	Operating
Phoenix, Arizona	Arizona Bio-chemical Co.	Dano	272	300	Mixed refuse	1963	Closed (1965)
Sacramento Co., California	Dano of America, Inc.	Dano	36	40	Mixed refuse	1956	Closed (1963)
San Fernando, California	International Disposal Corp.	Naturizer	63	70	Mixed refuse	1963	Closed (1964)
San Juan, Puerto Rico	Fairfield Engineering Co.	Fairfield-Hardy	136	150	Mixed refuse	1969	Closed (1972)
Springfield, Massachusetts	Springfield Organic Fertilizer Co.	Frazer-Eweson	18	20	Garbage	1954 1961	Closed (1962)
St. Petersburg, Florida	Westinghouse Corp.	Naturizer	95	105	Mixed refuse	1966	Closed (1971)
Williamston, Michigan	City of Williamston	Riker	3.6	4	Garbage, raw sludge, corn cobs	1955	Closed (1962)
Wilmington, Ohio	Good Riddance, Inc.	Windrow	18	20	Mixed refuse	1963	Closed (1965)

materials. A screw press is used to reduce the moisture content of the shredded separated refuse to approximately 58 percent before going into the digester.

The Fairfield-Hardy digester is shown in Figure 3-71. It should be noted that the material is fed into the digester from the top around the outer cylindrical wall of the digester. After the material has been loaded into the digester, air is blown through the perforated bottom plate. This keeps the mixture in an aerobic state. The composting material is agitated by means of a number of augers. The augers are attached to a rotating bridge arm. These augers on the rotating arm do three things: one, blend the new wet pulp into older compost material; two, continually mix, aerate and turn over the material; and three, move the material toward the center of the digester for removal by the standpipe.

After an average or nominal period of 5 days of the digestion process the compost has moved to the middle of the tank and is removed. The material is then windrowed for about 3 weeks for curing. After the curing is complete, it is moistened with a starch suspension, granulated, and dried. After drying, the compost is screened and bagged.

The system has relatively high operating costs, especially with respect to the digester. The rotating bridge with the augers for agitation must run continuously. A second major disadvantage is that the only way to expand the plant is to build another complete digestion tank.

Table 3-40 provides an estimate of the capital costs, energy, and labor needed to build and run different size plants. In each case, the digester is designed for the total plant capacity.

The economic aspects of the Fairfield-Hardy composting process are fairly representative of the majority of aerobic processes. Since there are very few plants in actual operation, (see Glysson, et.al., ref. 3-92) the cost data available in the literature is somewhat limited and dated. An example of this is the 1968 Johnson, City data (ref. 3-90). Table 3-41 presents the process cost for the Fairfield-Hardy composting process and gives the credits available for resource recovery (ref. 3-28). From the preliminary analysis of other composting processes, it is believed that

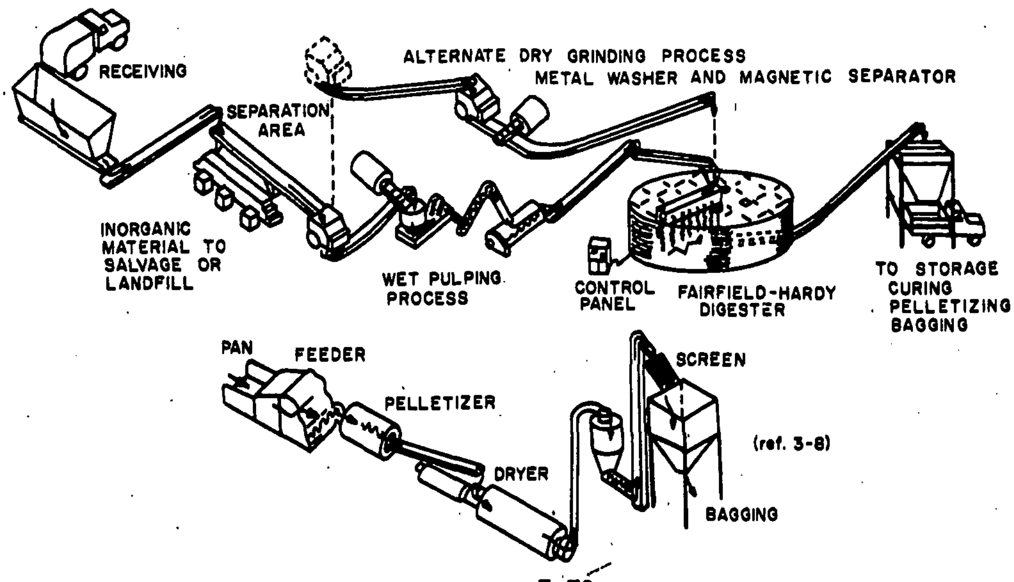


FIGURE 3-70
SCHEMATIC FLOW DIAGRAM FOR FAIRFIELD-HARDY COMPOST SYSTEM

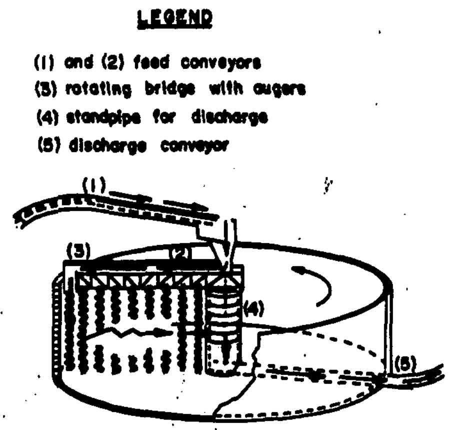


FIGURE 3-71
SCHEMATIC OF FAIRFIELD-HARDY DIGESTER

these cost figures are representative of the cost structure of composting systems in general. An analysis of cost data shows that while one process might use less power, it usually uses either more labor or land investment.

The $6.92/metric ton ($6.28/ton) cost of refuse disposal for the 907 metric ton/day (1000 ton/day) composting system seems to agree fairly well with earlier published data for similar but lower capacity systems (Figure 3-72). However, in

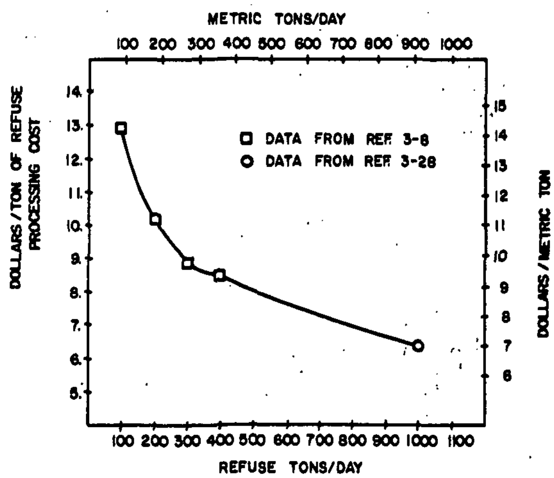


FIGURE 3-72
COMPOST COST DATA

TABLE 3-40
ESTIMATES OF CAPITAL COSTS, ENERGY, AND LABOR REQUIREMENTS FOR FAIRFIELD-HARDY COMPOST SYSTEMS*

Capacity metric ton/day	Capacity (tons/day)	Capital cost (dollars)	Power requirements kw	hp	Labor requirements (men)
91	100	1,370,000	694	930	11
182	200	2,000,000	1186	1590	18
272	300	2,510,000	1365	1830	25
363	400	3,210,000	1910	2560	30

*ref. 3-8

this case, if no market were found for the humus, the cost for processing MMR would only go from $6.92 to $8.58/metric ton ($6.28 to $7.78/ton). This additional cost might have to be paid by the community where all other options are much more expensive. Under proper economic subsidies, the humus could be given away or even landfilled. A discussion of the specifics of a particular market will be given in the Appendix.

In most cases, the compost plants have remained open only as long as a steady commercial market existed for the compost or a subsidy or grant artificially supported the operation. A major problem has been the humus market in larger metropolitan areas. The problem is simply that the volume of humus exceeds the compost market.

However, no detailed analysis has been done on developing a market for the compost as a replacement for peat moss. With proper preparation, advertisement, and pricing policies, the material might be able to compete with peat moss. An example of this is the processed sewage sludge from the Milwaukee Metropolitan Sewage District which is sold as a lawn fertilizer under the name of Milorganite. The community might not provide a total market for the humus produced, but the profit from the retail sale of packaged humus can be used to dispose of the remainder. Let us consider a specific example. Most major population areas are shipping centers. Therefore, grain is moved into these regions on the railroads in either hoppers or box cars from the grain belts. Suppose the additional humus is shipped to the grain belt in the empty hoppers or box cars. Here the humus could be sold to farmers for some price determined by the nutrient value of the elements in the humus. This price could be set at in economically viable level. The loss on this operation would be matched against the profit from the retail bagged humus sales in the urban area. A detailed market analysis of this suggestion needs to be done in order to determine if the market can be created to make the operation economically feasible.

3.5.3 Methane Production Process

Ideally, all solid waste would be recycled or converted into useful products with high marketability. One such product is methane and the following discussion of methane production will follow this general outline: introduction, small systems, industrial and MMR systems, and a recovery system for sanitary landfills.

3.5.3.1 GENERAL INTRODUCTION

The general introductory comments on the theoretical considerations of methane production are based mainly on refs. 3-93, 3-94, and 3-95.

The anaerobic decomposition of any complex organic substance is basically a two-stage process. The first stage consists of the breakdown of the complex organic materials in MMR by acid formation bacteria into organic acids with the production of CO_2. These organic acids in the second stage are acted on by bacteria known as methane formers to produce CH_4 and CO_2.

In the reduction of organic material by anaerobic digestion, the organic complexes are acted upon by a group of floccules and anaerobic bacteria known as acid formers. The organic fraction of the MMR consists of proteins, carbohydrates and fats. This material undergoes the acid fermentation which converts 35 percent of the material into shortchain organic acids. This consists of 15 percent being converted into propionic acid and 20 percent being converted into acetic acid. The other 65 percent of the organic material is converted into alcohols, aldehydes, and long-chain fatty acids. These percentages are not exact and depend

TABLE 3-41
ECONOMIC DATA-FAIRFIELD-HARDY COMPOST SYSTEM
PROCESS COST SHEET

PROCESS NAME: Similar to Fairfield-Hardy Compost
DATA SOURCE: Ref. 3-28
CAPACITY IN TONS/DAY: 907 metric tons (1000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land	$ 400,000a	a Includes site improvements
Preprocessing Eqmt	1,730,000	
Processing Eqmt	5,500,000	
Postprocessing Eqmt	940,000	
Utilities	No detail	
Building & Roads	No detail	
Site Preparation	b	b See land cost
Engr. & R & D	1,748,000	
Plant Startup	153,000	
Working Capital	229,000	
Misc.:	6,400,000c	c Auxiliary and support facilities
TOTAL	$17,100,000	
OPERATING COSTS ($ PER YR)	d	d Assumes 300 day/year
Maint. Material		
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead		
Utilities	$ 1,132,000e	e Total operating cost
Taxes		
Insurance		
Interest		
Disposal of Residue		
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	$ 1,132,000	
CREDITS ASSUMED ($ PER YR)	$ 1,103,000	

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid		
Gas		
Solid	NONE	
Power:		
Steam		
Electricity		
Hot Water	NONE	
Magnetic Metals	$ 245,000 a	a No credit $/ton detail given
Nonmagnetic Metals	240,000	
Glass	168,000	
Ash		
Paper		
Other: Humus	450,000	
TOTAL ($ PER YR.)	$1,103,000	

on the composition of the MMR.

The initial stage of methane production or the acid-fermentation is essentially a constant BOD (biological oxygen demand) stage because the organic molecules are only rearranged. Thus, in the general case, the energy production by this step is very low and the microorganism growth is also low. Since most of the energy produced is used by the bacteria for growth, there is minimal energy liberated from the system. The first stage does not stabilize the solid waste, but it is essential for the second stage by converting the organic material to a form usable by the methane producing bacteria.

The second stage takes place when anaerobic methane forming bacteria act upon the short chain organic acids. In this stage, the short chain organic acids undergo methane fermentation with CO_2 acting as a hydrogen acceptor and being reduced to CH_4. The methane formed, being insoluble in water, escapes from the system and can be used for a fuel. The production and loss of methane cause the stabilization of the organic material. Since methane has a high energy content, most of the energy of the system goes into methane gas and not into the production of large amounts of cell mass and solids. Each cubic meter of methane produced at standard temperature and pressure removes 2.9 kilograms of COD or BOD (1000 cubic feet of CH_4 at standard temperature and pressure removes 178 pounds COD or BOD).

The methane producing bacteria consist of several different groups. Each group has the ability to ferment only specific compounds. Therefore, the bacterial mixture in a methane producing system should include a number of different groups. When considering retention times of solids, the rate of bacteria production becomes important. For periods of 10 to 15 days of retention time, the rate of reduction is limited by methane fermentation. For systems where the retention time is longer than 15 days, the rate limiting aspect is then the hydrolysis of organic solids.

The actual destruction of organic material in MMR is directly related to the production of methane. An equation has been developed to predict the theoretical quantity of methane from the chemical composition of the waste.

$$C_nH_aO_b + (n - a/4 - b/2)\ H_2O \rightarrow$$
$$(n/2 - a/8 + b/4)\ CO_2 + (n/2 + a/8 - b/4)CH_4$$

Since a typical empirical chemical formula for the organic portion of MMR is given by:

$$C_{30}H_{48}O_{19}N_{0.5}S_{0.05}$$

we can determine a theoretical methane value.

$$C_{30}H_{48}O_{19} + (30-48/4-19/2)\ H_2O \rightarrow$$
$$(30/2-48/8+19/4)\ CO_2 + (30/2+48/8-19/4)\ CH_4$$

Since this calculation is approximate, the results can be given as:

$$C_{30}H_{48}O_{19} + 8.5\ H_2O \rightarrow 7.3\ CO_2 + 22.7\ CH_4$$

This means that if you consider 1 metric ton of MMR, with an assumed organic content of 50 percent, the amount of water needed for the reaction is 112 kilograms (246.6 pounds), and the methane fermentation will produce 210.5 kilograms (464 pounds) of CO_2 and 298.7 kilograms (658.5 pounds) of CH_4. Since the slurry must be approximately 60 percent water for the methane bacteria, the water added per ton, assuming 24 percent initial moisture content, is approximately 200 kilograms (440 pounds) per metric ton. Obviously the system will not in general convert all the organic material in MMR to methane. Not only does the methane production depend upon the composition of the waste, but on a number of other environmental conditions. These conditions are temperature, reducing environment pH, nutrients, and nontoxic conditions.

One of the most important operational parameters is the temperature in the reaction vessel. Increasing temperature will increase the rate of reaction. There are, depending on the methane bacteria present, two optimum temperature ranges. Mesophilic bacteria produces methane in the temperature range from 30°C (86°F) to 37.5°C (100°F) while thermophilic bacteria produce methane in the temperature range from 49°C (120°F) to 51°C (124°F). The reaction rates are much higher for thermophilic processes, but energy in the form of heating must be introduced into the system in order to maintain these temperatures.

The introduction of even small amounts of oxygen into the system will change it from a reducing environment and destroy the methane formers since they are strict anaerobes. Like most organisms, methane bacteria prefer pH values in the range of around 7.0. The actual range of optimum pH values are 6.6 to 7.6, and below 6.2 the acid conditions are quite toxic to methane bacteria, even though the acid forming bacteria will continue to grow. The C/N ratio values are similar to those for aerobic bacteria, and again sewage sludge can be used to provide nutrient and nitrogen enrichment. The final requirement is that the system is free from toxic materials either in the form of inorganic salts or toxic organic compounds. This is a major problem in the case of MMR.

3.5.3.2 SMALL SCALE METHANE PRODUCTION

Examples of small scale methane production are seen in the work of Singh (ref. 3-9), Fry and Merrill (ref. 3-97) and in articles in magazines such as the Mother Earth News (ref. 3-98, 3-99, 3-100, and 3-101). While these are quite informative with respect to the methane production process, the application of these systems to MMR are limited. The use of these small systems should be considered for isolated regions, third world countries, or regions without energy resources.

One should also note that the same sanitary and zoning laws which control or prohibit outside toilets, septic tanks, individual wells, and trash burning in municipal regions would also, in most locations, presently apply to the backyard methane generator.

3.5.3.3 INDUSTRIAL AND MMR METHANE PRODUCTION SYSTEMS

The large scale production of methane can be considered with respect to two material sources. These are the industrial system and the municipal waste collection system. By industrial waste, we mean not only that from industrial complexes in the petrochemical sense, but also from food processing plants and agribusinesses. The agribusiness category includes chicken brooder houses and cattle feed lots.

There are a number of feed lot operations either considering or entering the area of methane production from cattle manure. The general biological reduction process is obvious and has been outlined previously. Where one has a separate sewage system for a specific waste, the special processing of this waste for maximum recovery value should be considered. An example of a system where methane production is applicable is Omaha, Nebraska. In Omaha, there are 18 major feed lots, and they are on a special sewer for their wastes. Here the special or separate processing of cattle manure would be the best economic approach.

With respect to methane production from MMR, we will consider the Pfeffer-Dynatech anaerobic digestion system. Even though a working plant prototype system is not now in existence, the system is well researched and is based on proven systems which produce methane from sewage sludge. The Pfeffer-Dynatech system is essentially similar to all of the other proposed methane production systems. In its basic aspects it is a scaled up version of Singh's backyard system with the obvious changes for the plant size and the use of MMR as the feed.

3.5.3.4 PFEFFER-DYNATECH ANAEROBIC DIGESTION

The anaerobic digestion process developed by Pfeffer (ref. 3-95) and Wise, et.al. (ref. 3-102) considers the reclamation of energy from organic refuse by the production of methane. The methane production process also produces fairly large amounts of carbon dioxide. Separation of the CO_2 from the CO_2 - CH_4 mixture of gas produced by the digester, gives a burnable fuel gas grade product. Since the predominant organic component of MMR is cellulose, the stoichiometry is :

$$C_6H_{10}O_5 + H_2O \rightarrow 3CO_2 + 3CH_4$$

Anaerobic digestion as described by the above equation decomposes 1 kilogram of MMR into 0.41 cubic meters of CH (1 pound of MMR into 6.65 cubic feet of CH_4) at standard conditions. The CH_4 will be accompanied by an equal volume of CO_2, ie., 1 kilogram of MMR will also produce 0.41 cubic meters of CO_2.

The process can be described best by use of Figure 3-73. This figure shows, by means of a block diagram, the major components of the Pfeffer-Dynatech anaerobic system. Methane gas production from MMR can be divided into four distinct and separate operations. These consist of MMR handling, digestion, gas treatment, and effluent disposal.

The MMR, handling consists of taking the solid waste as delivered to the plant, and shredding it by means of dry primary shredders. This reduces the maximum MMR particle size to a range from 7.6 centimeters (3 inches) to 15 centimeters (6 inches). A magnetic separator removes ferrous metals followed by a Trommel screen to remove the fine grit. The waste stream can then be passed through a hydropulper and then cyclone separators to reduce the size and remove nonferrous metals and glass. The second possibility is an air classifier for glass and nonferrous metal removal followed by a second dry shredder. The final ideal particle size is less than 2.5 centimeters (1 inch). The remaining fraction of the MMR stream, the organic matter, is then slurried with aqueous nutrients, pH control additives in the form of lime, and hydrogen sulfide control additives in the form of ferrous salts. This mixture is then fed into the digester.

The proposed system consists of a number of separate large digester tanks. Each tank is maintained at constant pressure by a floating cover. The circular tanks are constantly stirred to maintain an approximate constant density of suspension and thus uniform digestion. The digestion

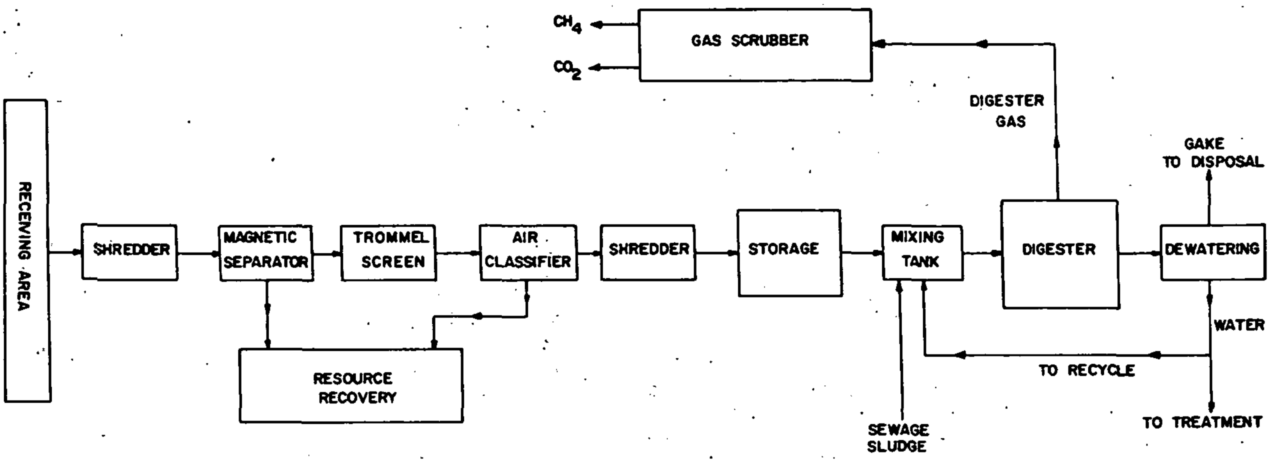


FIGURE 3-73
BLOCK DIAGRAM OF THE PFEFFER - DYNATECH ANEROBIC DIGESTION SYSTEM

process is carried out in two steps. First the solids are solubilized by enzymatic action. Second, these soluble products are digested by the microorganisms to produce CH_4, CO_2, and small amounts of other gases such as H_2S. The cleanup of the gas to remove the acid fraction would utilize natural gas technology. The effluent production by the process, especially if it is continuous, produces a problem. Even though the biological mass could be reclaimed and recirculated into the digester, large amounts of water must be cleaned up and disposed of continuously. The other problem is to dispose of the remaining digested solids.

The economics of the Pfeffer-Dynatech system are based on the experimental work of Pfeffer and the scaled up pilot plant data by the Dynatech corporation. The process costs and the resource recovery data are itemized in Table 3-42. The pilot plant information has been scaled up to the 907 metric ton/day (1000 ton/day) information given in these tables. The following pertinent details are condensed from ref. 3-102.

1. The estimates will vary with conditions at a particular time and place. However, a base-line model for operating costs is developed. This model uses the following unit cost estimates:

Power	$2.78/10^9 joules	($0.01/KWH)
steam	$.95/10^9 joules	($1.00/million BTU)
cooling water	$5.30/10^6 liters	($0.02/thousand gallons)
lime	$27.56/ metric ton	($25.00/ton)
labor (28 men)	$5.63/man-hour	
supervision (4 men)	$6.63/man-hour	

disposal costs:

Incineration of dewatered cake	$33/metric ton	($30/ton dry solids)
landfill of inorganics	$1.38/metric ton	($1.25 ton)
sewage treatment of water	$5.30/10^6 liters	($0.02/thousand gallons)

2. An estimate is made of the selling price of the methane to achieve a 15 percent return on the equity for a private investor

TABLE 3-42
ECONOMIC DATA-PFEFFER-DYNATECH METHANE GAS SYSTEM
PROCESS COST SHEET

PROCESS NAME: Pfeffer-Dynatech Anaerobic Digestion
DATA SOURCE: Dynatech Report (Ref. 3-102
CAPACITY IN TONS/DAY: 907 metric tons (1000 tons)

	DOLLARS	COMMENTS
CAPITAL COSTS (TOT. $)		
Land	(a)	(a) Not included
Preprocessing Eqmt	1,879,300	
Processing Eqmt	2,620,693	
Postprocessing Eqmt	3,062,218	
Utilities		
Building & Roads	500,000 (b)	(b) Building only
Site Preparation		
Engr. & R & D	502,947	
Plant Startup	75,403	(c) Contingencies
Working Capital	48,066	(d) Interest during construction
Misc.:	2,342,058 (c)	
	2,191,688 (d)	(e) Expense & profit - contractor
	1,760,316 (e)	
TOTAL	320,246 (f)	(f) Plant equipment
TOTAL	15,302,935	
OPERATING COSTS ($ PER YR)		
Maint. Material	194,817	
Maint. Labor	187,008	
Dir. Labor	249,344	
Dir. Materials	82,815	
Overhead	319,264	
Utilities	356,818	
Taxes (Local) Insurance	350,670	
Interest		
Disposal of Residue	1,969,424	
Payroll Benefits		
Fuel		
Misc.:		
TOTAL	3,770,160	
CREDITS ASSUMED ($ PER YR)	5,714,791	

	DOLLARS/YR.	COMMENT
Fuel:		(a) Not calculated in report-calculation done based on 330 day/yr and \$.935/10^9 joules (\$.987/10^6 Btu-report figure)
Liquid		
Gas Methane	1,240,000 (a)	
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals	343,195 (b)	(b) 18.70/metric ton (17.00/ton
Nonmagnetic Metals	(c)	
Glass	(c)	(c) Glass & non ferrous metals assumed landfilling
Ash		
Paper	(d)	
Other: Sewage sludge	618,502 (e)	(d) Light organics landfilling
Disposal credit	3,513,094 (f)	(e) \$55.00/metric ton (50/ton)
TOTAL ($ PER YR.)	5,714,791	(f) City pays 11.70/metric ton (10.65/ton)

A standard gas utility method is employed assuming:

period of depreciation	20 years
depreciation method	5% on total capital-straight line
federal income tax rate	48%
percent interest on debt	9%
debt/equity ratio	75%/25%

The cost model allows recovery credits only for ferrous metals as the inorganics are assumed landfilled. The other credits are for disposal of municipal sewage sludge and the refuse itself.

Credits are as follows:

ferrous metal	18.74 /metric ton ($17.00/ton
disposal of sewage sludge	55.13/metric ton ($50.00/ton)
disposal of municipal wastes	11.74/metric ton ($10.65/ton)

The calculation of the methane selling price is as follows:

	10^9 Joules of Methane	10^6 Btu of Methane
contribution of capital costs	$1.52	($1.602)
contribution of oper. costs	$1.49	($1.573)
penalties:		
filter cake disposal	$1.53	($1.610)
waste water treatment	$ .01	($0.010)
inorganic waste disposal	$ .09	($0.100)
total costs	$4.64	($4.895)
credits:		
scrap iron	$ .28	($0.300)
sewage sludge disposal	$ .51	($0.540)
municipal waste disposal	$2.91	($3.070)
total credits	$3.70	($3.910)

The selling price of the methane is then the difference between costs and credits or $.94/10^9$ joules ($0.985/10^6$ Btu).

3. Any variation in the cost or credit items would change the selling price. The report indicates that the selling price of methane needed is most sensitive to the credit received for solid waste disposal. In reality, this credit will also vary widely from place to place. A wide spectrum of waste disposal costs are experienced across the country from 2.21/metric ton ($2.00/ton) in a landfill to as high as $28.66/metric ton ($26.00/ton) in an incinerator.

4. To help a local region decide on the feasibility of this system for waste disposal, graphs such as Figure 3-74

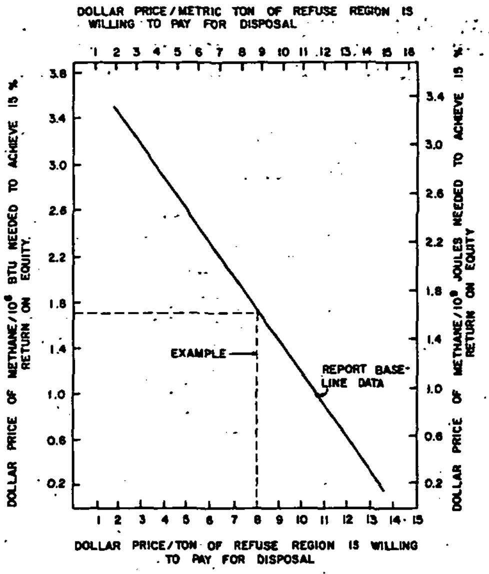


FIGURE 3-74
VARIATION OF METHANE PRICE NEEDED WITH MUNICIPALITY LOCATION

might be developed. The needed selling price of methane is shown vs. the price per ton a municipality is willing to pay for refuse disposal. Based on this example graph, a community willing to pay $8.82/ metric ton ($8.00/ton) for refuse disposal would necessitate the private investor selling his methane at $1.61/10^9$ joules ($1.70/10^6$ Btu). If the current or near term price of natural gas in this area is only $0.95/10^9$ joules ($1.00/10^6$ Btu), the feasibility of this disposal system is clearly questionable.

4. Since carbon dioxide is also produced, the credit situation could be improved if a suitable market were available. The plant theoretically produces 227 metric ton/day (250 ton/day) of carbon dioxide and 86 metric ton/day (95 ton/day) of methane. Chemical companies are currently paying about $8.821 metric ton ($8.00 per ton) for 98% carbon dioxide with no sulfur content. If the carbon dioxide is then purified to 99.9%, it may be sold for up to $149/metric ton ($135.00/ton). This added credit, depending on the purity of carbon dioxide, would shift the graph down to the left indicating a lowered selling price for methane.

5. Another set of credits may be obtained by adding other resource recovery equipment for the recovery of aluminum and glass.

6. A lower cost structure would also be

obtained if public financing is used.

7. The energy needs for the system are about 35 percent of the methane produced. A tradeoff analysis must be made concerning use of the methane or purchase of power.

8. It is noted that the costs in this report are for a hypothetical 907 metric ton/day (1000 ton/day) system. The system itself is only in the bench scale stage. The Dynatech researchers, however, have made attempts to achieve reliable figures based on current equipment prices and accounting procedures.

3.5.3.5 METHANE RECOVERY FROM SANITARY LANDFILLS (ref. 3-103)

Let us now consider some of the problems of sanitary landfill and a possible solution to these. Two specific problems to consider are the volume in landfill and the production of gases by the MMR in the landfill. The solution proposed is a modification on a system developed by NRG Nu Fuel Company of Newport Beach, California. In this suggested proposal, the two problem solutions are interrelated.

The first problem is that of landfill volume needed for MMR. The suggested solution to this problem is to use a preprocessing system which will remove ferrous metal, glass, aluminum, and some newspaper. A Black-Clawson type recovery system could be used which could reduce the volume by approximately 2/3. The remaining portion would be mainly organic.

If one considers the history of gas production in the compacted cell of a sanitary landfill, Figure 3-75, one notices

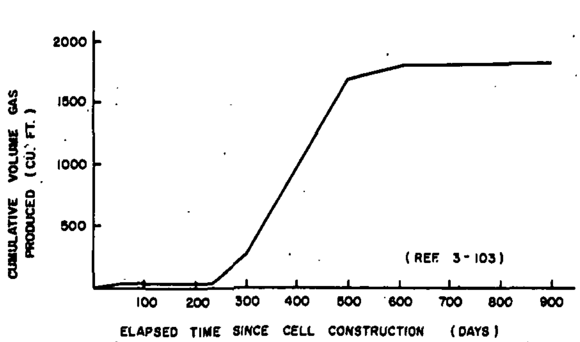


FIGURE 3-75
GAS PRODUCTION FROM AN EXPERIMENTAL SANITARY LANDFILL

the increase of gas production with time. Also an analysis of the gas content with time, Table 3-43 shows that the organic material progressively goes to an anaerobic condition. This production of methane, which can last over a period of 10 years for a 10^6 cubic feet/day landfill, is a major problem with respect to all sanitary landfills.

TABLE 3-43
LANDFILL GAS COMPOSITION*

Time interval since Start of cell completion (months)	Average percent by volume N_2	CO_2	CH_4
0-3	5.2	88	5
3-6	3.8	76	21
6-12	0.4	65	29
12-18	1.1	52	40
18-24	0.4	53	47
24-30	0.2	52	48
30-36	1.3	46	51
36-42	0.9	50	47
42-48	0.4	51	48

The final solution involves considering both of these problems. The remaining fraction of the MMR which is mainly organic is mixed with some small amount of dried sewage sludge and compacted in a specially-prepared sanitary landfill. In this landfill, some form of leachate barrier, plastic asphalt, etc., is placed in the bottom and along the sides. The landfill is then filled with compacted, enriched, and separated MMR. During the construction of the landfill, radial distribution tiles and vertical well shafts are constructed, keeping the system closed, as necessary. Thus when the sanitary landfill is completed, a system of gas collection wells with radial access is already in place. The landfill is then sealed with an air and water tight cover. Moisture levels in the sanitary landfill are then raised to optimum levels by pumping water into the gas wells. The sanitary landfill is allowed to become a large anaerobic digester producing CO_2 and CH_4. Since both of these gases are now recoverable and salable, markets should be available. After the process of biological degradation is complete, approximately 10 years or more, there are two possible uses for the site. The wells can be sealed and the land surface recovered for use, or the humus can be dug out and used for soil conditioning. In the latter case, the sanitary landfill site can be used again. This proposed system deserves further study.

3.5.4 BIOCHEMICAL PROCESSES

Biochemical processing by definition means that the characteristic chemical aspects of specific biological organisms are employed to process and thus convert organic material. The biological organisms considered here will always be microorganisms usually in the form of bacteria, protozoa, or fungi. These microorganisms are processing the organic material for their own metabolic needs. This means that either their waste products must be useful or the process must be modified to collect useable and useful byproducts.

The application of biochemical processing to the MMR problem means that highly complex technology is applied to the solid waste problem. The use of this technology is applied to the solid waste problem. The use of this technology requires the use of explicit equipment and sometimes sizable power demands inherent in the process. Another problem with biochemical systems is the type of feed they are designed to accept. Industrial grade process feed is usually highly homogeneous and controllable with respect to the composition. However, MMR is highly heterogeneous and virtually uncontrollable with respect to composition. This leads to an obvious conflict with respect to processing methods.

The next major problem with respect to biochemical processing of MMR is that of toxic materials. Metallic salts, organic cyanide compounds, and industrial solvents are examples of the toxic substance which can poison a biological system. Since biochemical systems are generally expensive, the value of the final product must of necessity be sufficient to recover some of this cost. Thus most biochemical processes are being developed to produce a food source. Because of FDA regulations the food is fed only to domestic livestock. This means that the toxic material can do one of two things. First, the poisonous material can kill the microorganisms and/or poison the plant. Since most of the biochemical processes are either continuous or semi-batch, this poisoning could significantly affect the system. Second, the toxic materials, in low levels, might be metabolized or absorbed by the microorganisms. As the toxic material moves up the food chain, the classical cumulative effect will take place. This could lead to lethal dosages in the ultimate consumer with similar effects. Two major examples of this would be pesticides such as DDT and heavy metals such as lead. Now that problems inherent to the biochemical processing of MMR have been discussed, let us consider the other major problem with this approach.

Studies done to date have been conducted on a small scale using laboratory equipment or using experimental input as a substitute for MMR. Each of these problems can be considered in some detail. The problems with respect to the lack of research using MMR may be grouped into two basic categories. The first category includes those processes which were developed for specially selected material and for which the authors now suggest MMR as an acceptable substitute. In these cases, further experimental studies must be done in order to verify these claims. The second category includes those processes which are designed to reduce a specific material. The consideration should be on the optimum use of the feed material. In other words, are there other uses for the material which require less total energy consumption and are more economically viable than the proposed new use? The following sections will consider one specific example of each type.

The major emphasis in biochemical processing has been in the area of the conversion of organic solid wastes into yeast or fungal protein as illustrated by the works of Meller (ref. 3-104) and Rogers, et.al. (ref. 3-105). These studies are based on the existing and viable yeast dependent industries such as brewing. The studies done so far consider pilot plants or computer modeling of plant processes.

As Schulz notes (ref. 3-21), complete economic feasibility data will not be available until studies are done on the use of MMR as the cellulose source for feed to an integrated hydrolysis and/or fermentation plant. The research done so far has been on the production of ethanol by the anaerobic digestion of MMR by yeast or the aerobic culture of yeast as a protein source for the use as a supplement in livestock feed.

The first potential market is the yeast conversion of MMR cellulose to a liquid fuel, namely ethonol. This has historically been the method used to produce ethanol. However, since World War II, ethylene from the petrochemical industry has been the product used for the production of ethanol. If the total MMR of 1.8×10^8 metric ton/year (2×10^8 ton/year) were ultimately converted to ethanol, the total yield would be 1.82×10^{10} liters (4.8×10^9 gallons) of ethanol. If the economics are viable, the market can easily absorb this amount of additional ethanol. However, the price of the fermented ethanol production is not competetive with existing prices.

The production of protein from yeast has been of considerable interest for a number of years, but the quality and the cost of the sugar needed for fermentation have made this method of protein production uneconomical. Considerations of MMR as a possible nutrient source have led to a number of studies.

The isolation of a specific yeast strain, the Torula strain, which will consume both pentose and hexose, makes the reduction of MMR to protein possible. The two sugars are end products of cellulose hydrolysis. Even though yeast protein is currently produced on a continuous industrial scale in Europe and Japan, the substrate used is not MMR. The lack of actual studies and pilot plants on the production of yeast protein from MMR is the major stumbling block to full scale use of this method.

The yeast produced as a protein supplement for animal feed would have to compete with both fishmeal and soybean meal. At the current prices for these two commodities, yeast protein is still more expensive, even with the inexpensive cellulose source that MMR provides.

To show both some of the problems and the promise, we will consider two specific processes. One, the production of protein from bagasse. And two, the production of glucose from cellulose.

3.5.4.1 PROTEIN PRODUCTION

The production of single cell protein by use of a specially designed chemical microbial plant applied to bagasse has been studied by a group under the direction of Callihan and Dunlap (ref. 3-106). The purpose of the study was to take previous laboratory data and apply these results to a pilot plant. From this pilot plant, both sizing and economic studies could be done to determine the expected characteristics for a full-sized industrial plant.

The pilot plant was designed so that the fermentation operation could be carried out using both batch and continuous flow production. The general flow sheet for the pilot plant is given in Figure 3-76. The plant's equipment is grouped into five distinct operational aspects: cellulose handling, treatment, sterilization, fermentation, and cell harvesting.

In the initial processing step, the size of the material is reduced. This is done using a five bladed knife grinder fitted with a 0.32 centimeter (1/8 inch) sizing screen. This unit has a capacity of 136 kilogram/hour (300 pound/hour) to 181 kilogram/hour (400 pound/hour). The chopped cellulose is then blown into a hopper and passed to the second stage.

The second stage consists of a slurry tank to undergo alkali contracting. The temperature range is controllable from ambient room temperature to the boiling point of water 100°C (212°F). The slurry is then dewatered by separating the liquids

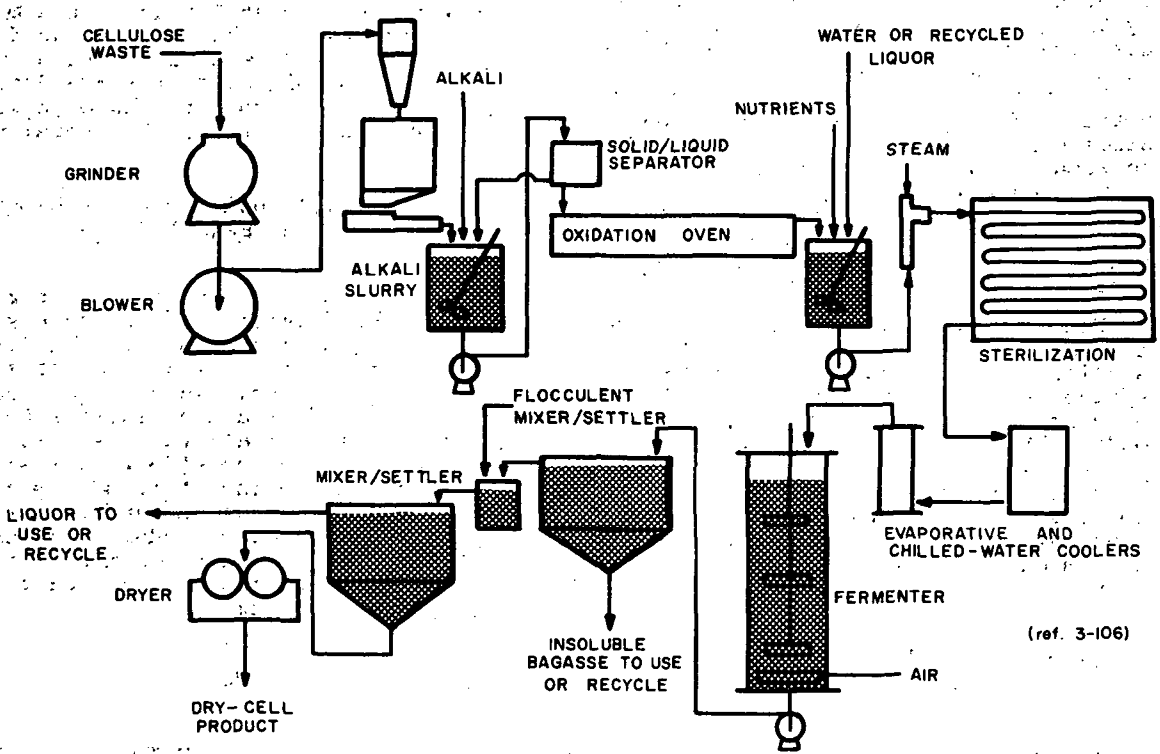


FIGURE 3-76
PILOT-PLANT FLOW SHEET FOR PRODUCTION OF SINGLE CELL PROTEIN

and solids. The cellulose solids are then passed through an oxidation oven before being mixed with nutrients.

The third stage consists of sterilization of the cellulose, followed by cooling before injection into the fermentation tank. The heart of the system is the fermentation tanks which contain the microoganisms, in this case cellulose utilizing bacteria such as cellulomonas, which turn the feed into protein.

The rest of the plant is used to separate out the insoluable fraction and to recover the dried cell product. In this plant this is single cell protein.

The pilot plant was specifically designed to process sugarcane bagasse. For this specific type of feed the operating economics of this size plant can be considered. An input of 48 metric ton/day (53 ton/day) will produce 15 metric ton/day (16.7 ton/day) of protein and 9 metric ton/day of cattle feed. This means that every metric ton (1.103 ton) of bagasse can be converted into 0.31 metric ton (0.35 ton) of protein and 0.19 metric ton (0.21 ton) of cattle feed. For a 27 day month, a 453.5 metric ton/month plant corresponds to a 16.8 metric ton/day (18.5 ton/day) operation. Also a 907 metric ton/month (1000 ton/month) plant corresponds to a 33.6 metric ton/day (37.0 ton/day) operation. The pilot plant study operating costs, as reported by the MRI Report, Vol. II, (ref. 3-28) are given as $0.284/kilogram ($0.129/pound) for 16.8 metric tons/day and $0.235/kilogram ($0.1065/pound) for 33.6 metric tons/day for the protein product. Since plant expenses are not broken down between actual running plant and instrumented pilot plant, the scaling factor is not known. In addition to the economics of the operation there are some other fundamental questions which must be answered.

The first problem with this process is that it is designed and developed specifically for bagasse. If this system were to be considered for the biochemical conversion of MMR, extensive modifications would need to be made, primarily in the preprocessing front-end system. This energy and equipment cost coupled with the low production yield of protein would not make this process economically viable in the forseeable future.

3.5.4.2 GLUCOSE PRODUCTION (Ref. 3-107, 3-108, 3-109)

The conversion of cellulose to glucose and thus to other materials also offers a possible method of recovering energy from cellulose and waste paper fractions of MMR. An example of this type of research is that being done by the U.S. Army at Natick Laboratories by Mandels, Spano, Reese, and others. The enzymatic hydrolysis of cellulose is based on the use of a biological catalyst. In the case of this work, cellulose enzymes are used to hydrolyze cellulose to glucose.

Since the enzyme is produced by fungus such as trichoderma viride for their own food production, the enzyme must be extracted from the fungus, or it will also consume the sugar. Because the hydolysis process is biological, it is low temperature. Also the separate use of the enzyme protects the fungi from toxic poisoning by MMR. The group is doing work with a rapidly growing mutant form of trichoderma viride. In general, enzyme hydrolysis plants require relatively high fixed capital costs with respect to acid hydrolysis.

Detailed studies of preprocessing, sizing, and feed composition on the conversion time from cellulose to glucose need to be made for many different types of materials and especially for MMR. Hopefully the description of the pilot test plant will soon be readily available in the published literature. The results of the detailed studies of materials, especially MMR, will enable a determination to be made of the range of applicability for enzymatic cellulose hydrolysis.

Since enzymatic hydrolysis is still in the developmental stage, much more research needs to be done. Also further research should be done on mutant microorganisms or mixtures of these designed specifically to convert the organic portion of MMR more efficiently to useful products.

3.5.5 CRITICAL ASSESSMENT OF BIODEGRADATION SYSTEM ALTERNATIVES

The separate sections on composting, methane production, and bioconversion include suggestions on additional areas of study either from a technical or an economic perspective. In this section, certain critical assessments of the biodegradation system alternatives will be made. The major considerations will be with respect to the state of the art and the inherent advantages and disadvantages of the particular methods. References 3-110 and 3-111 contain additional information related to the overall solid waste management problem.

3.5.5.1 COMPOSTING

In composting, overall general studies such as that done by McGauhey (ref. 3-112) are available. Even though these studies are not always either inclusive or specific, certain general trends with respect to composting systems can be identified. Evaluation of the status of composting research and the history of composting raises certain questions. The basic question to be asked is whether the composting process is at the present time a viable solution to the MMR problem.

Research money is still being spent on developing methods for composting rate acceleration using forced air systems. The earlier research in Europe and the United States raises questions as to the long term economic viability of such systems. Also because of previous work, the areas of viable composting research should be limited primarily to other possible biodegradation systems and/or microorganisms which can enhance the process with respect to either speed, breakdown efficiency or final quality of the organic product. Full-size experimental plants need funding if appropriate engineering studies are to be done. These studies could also include possible alternative subsystems. The use of full size plants would allow a study of actual operating problems over extended plant use. The composting plants can be scaled to any needed size, since there are no inherent limits imposed by the biophysics. All limits are determined by economic and social parameters. Thus only limited research is needed with respect to plant sizing economics.

Research on new alternatives is possible. Because of the unique composition of MMR, the study of possible inoculum development using mutations of composting bacteria should be considered. Also designing of plastics and synthetic materials for easier biological decomposition should be investigated specifically with respect to microorganism breakdown by either aerobic or anaerobic digestion.

3.5.5.2 METHANE PRODUCTION

The production of methane from MMR is always the result of the anaerobic decomposition of the organic fraction of the solid waste. Since the methane bacteria require an oxygen deficient or reducing atmosphere, the methane production process requires an isolated air tight environment in which to ferment the MMR.

Because of the high energy content of the CH_4, only small amounts of the energy goes into producing more microorganisms. Therefore, at least 15 days minimum time is required in order to reduce an appreciable percentage of organic material to methane. Methods of increasing the growth rate of the microorganisms would shorten this time. Research thus needs to be done on the development of mutant anaerobic methane forming bacteria or groups of bacteria to increase the speed of decomposition. If mutant or special bacteria mixtures could be developed, then the shortened time for stabilization of organic waste would make the inoculation of MMR economically more viable.

Since the microorganisms in anaerobic decomposition attack the material from some point on the surface, the size of decomposable material is directly proportional to the decomposition. Therefore, the surface area per unit volume must be maximized. This means that the material should be as finely ground as economically possible. This fine grinding and separation in the preprocessing of the MMR or other material increases the cost of methane production greatly.

The advantage of methane production facilities is that they can replace part of the sewage treatment facilities. This is because sewage sludge is the optimum C/N ratio enricher for the separated ground organic portion of MMR. The problem is that the final decomposed material is still greater than 40 percent moisture and must be either used for liquid fertilizer or dewatered and the effluent purfied. Since the methane process is, for economic reasons, done at the lower temperature range from 30°C (86°F) to 37.5°C (100°F), the liquid fertilizer must be sterilized first if applied where pathogens would be dangerous.

Since no extensive pilot plants have been constructed, no economic data or engineering data exist on the use of methane digesters for the stabilization of MMR. More research using actual pilot plants needs to be done. Introductory pilot plant studies by Stanford University show that a large percentage of organic fraction is non-decomposable. Also, those parts of the MMR which float on the slurry and resist agitational mixing do not decompose as readily as the same material would if submerged. Thus the laboratory studies used to predict the volume of solids remaining seem to be too low when plant size is scaled up. The size of the complete MMR volume that would be processed at any one time for a large urban area dictates that the plants be tested first as part of an integrated MMR disposal network, or in areas with smaller populations.

The most promising area of application is the processing of specialized types of organic waste such as animal manure or food wastes. Here the technology is readily applicable and the environmental regulations are making these applications necessary. Plants developed for processing these homogeneous organic waste products should provide the engineering data needed to determine areas where further research efforts are required.

Application of the sanitary landfill concept to produce a large natural methane generator, where applicable, has the best cost benefit ratio since it does not have to compete with existing landfill costs. Also the recovered methane is essentually free when compared with current landfill cost accounting.

3.5.5.3 BIOCHEMICAL PROCESSES

At the present time, biochemical processes are still mainly in the research and engineering laboratory stage. They provide, with respect to MMR, interesting curiosities which suggest further study to determine if they have economically valid applications to the solid waste disposal problem.

The area that looks most promising for the application of biochemical processes is the conversion of either low grade homogeneous waste or potentially dangerous waste into more useful forms. In the case of low grade waste, this conversion turns the waste into a more valuable product. The conversion of dangerous waste is governed by safety factors and the need to deactivate dangerous materials into biologically benign substances or substances which are easier to dispose.

The biochemical conversion of solid waste to more valuable food or fuel products will have to compete with all other conversion methods. In this competition for material, the future energy and food needs will determine how a particular product is accepted and its cost. The acceptance of biological process solutions to the energy problem will still cause competition for specialized organic waste between methane production and biochemical processes.

The results of research now in progress and future research are going to determine the ultimate application and economic viability of biochemical processes.

3.5.6 SUMMARY

The previous section contains the critical assessment of the status and potential of the different biodegradation systems. In this section, the current applicability of the different biodegradation methods will be considered.

Composting, which has had a fairly consistent history of failure still has many unresolved difficulties. The most promising aspect is the front-end resource recovery of metal, glass, and some of the cellulose fibers. The remaining organic portion can then be composted to produce humus. Compared to true landfill costs, this system may be more economical in some areas. The comparison of composting costs to incineration or pyrolysis must be on an individual basis for each community. For small communities in metropolitan areas with populations of 50,000 or less, composting could offer potential economic advantages. For larger cities and regions composting does not appear to be an attractive method of disposing of solid waste.

Methane production has not yet been applied to the MMR of a community. Because of the volume of the waste produced by a large metropolitan area in a single day, the first applications of methane production will probably be limited to smaller communities, limited regions within a community, or specialized forms of agribusiness with their animal and plant wastes.

Biochemical processes have their most promising and most current applications in the area of hazardous waste disposal. The area of most need is the detoxification of organic poisons or organometallic compounds. Application of biochemical processing on a commercial level to MMR depends on further research and development.

In summary, biodegradation systems are not today readily applicable or economically viable to solve the MMR problems of the major metropolitan regions. Application of biodegradation methods to areas with smaller populations, in certain specialized situations, could be economically viable. This is because the most applicable method, composting, has a cost/unit mass price which is essentially independent of the size of the operation. This is in contrast to incineration and pyrolysis, which must have access to minimum regional solid waste production levels to be economically viable.

3.6 SUMMARY

A large number of technical options with energy recovery are currently available for use by a community. A number of other processes are in full-scale developmental stages, and information on their operations should start becoming available within the next 1-2 years. Communities facing a critical refuse disposal problem and who must therefore make an immediate decision on a solid waste disposal method should lean toward proven technology.

Incineration

Water-wall incinerators for energy recovery have the greatest total operating experience and can be considered a proven process. For them to be economical, however, a market must be available for the steam generated, and the steam selling price should be keyed to equivalent energy costs to allow for increases in the cost of energy.

The use of refuse as a supplemental fuel (as in the St. Louis project) looks very encouraging. The results are incomplete in St. Louis, and more evaluation is certainly necessary, particularly for combustion efficiency and emission controls. The economics of this process appear to make it the cheapest of all methods considered in this report for energy recovery from MMR. Very good data should be available within the next 12 months.

The use of sophisticated front-end systems to prepare refuse as a solid fuel for direct incineration has several advantages. The fuel is in solid form, is easily stored or transported, has a relatively high heating value, and may be pneumatically injected into a boiler for suspension firing. Prepared solid fuels such as Eco-Fuel™ II have not been processed on a large scale basis, so production or firing reliability has not been established. The particle size, for instance, for greatest firing efficiency for a given boiler has not been determined. This method of energy recovery from MMR is at least a year away from demonstrated feasibility on a prototype plant. A solid fuel from prepared refuse could be very economical in areas where the energy costs are high and sanitary landfills are not a viable option to the solid waste disposal problem.

The generation of electricity directly from incineration of refuse, as in the CPU-400 system, is still in the pilot plant stage. Too many unsolved problems have been encountered thus far, and the system has not yet reached the prototype stage of development.

Pyrolysis

Many different pyrolysis processes are currently available for energy recovery from solid waste. Several of the processes have been demonstrated on large-scale pilot plants (greater than 32 metric tons (35 tons per day), and at least five pyrolysis plants are being built on a commercial basis. Much more data should become available within a year, particularly from Baltimore's Monsanto Landgard plant and from Union Carbide's Purox plant. The economics will be a particularly important factor to consider in the new pyrolysis plants. The current economic data, by necessity, has to be scaled up from small pilot plants and involves a number of unknowns. If the plants can, in fact, operate as cheaply as the present economics predict, then pyrolysis processes will compete favorably with remote landfill disposal costs, as well as recover energy.

Pyrolysis, in general, offers the opportunity for producing either a solid, liquid, or gas, with most of the processes producing a gas; however, the heating value of the gas is generally much lower than pipeline gas. This requires the gas to be burned on site (or at a nearby plant); therefore, in the planning stages provisions will have to be made for the utilization of the product gas at or near the pyrolysis facility. The Garrett process produces a liquid fuel, which may be stored or transported. An uncertainty currently exists as to the potential corrosive nature of the fuel.

Although pyrolysis technology is not fully developed, this means of energy recovery from MMR will eventually prove to be the most versatile. Four distinctly different reactor processes are available, with variations in heating methods existing within those four categories. A wide choice of front-end systems is also available. If a particular community does not have a market for recycled materials, then a pyrolysis process like Union Carbide's Purox system might be selected. On the other extreme is the Garrett front-end system which would allow for recovery of both ferrous and nonferrous metals as well as glass. Local markets for energy and recovered resources will ultimately dictate the choice of the system to be selected and the economics of that system.

NAAS Pyrolysis Process

The pyrolysis concept discussed in section 3.4.6 offers a number of advantages and appears to have good economic potential. NAAS is a conceptual design only, however, and experimental work is needed to determine the feasibility of the system. The rotary kilns offer operational simplicity, and the use of indirect heating of the refuse by dolomite should give a high heat transfer rate and produce a fuel gas of moderate heating value. The major uncertainties in the system are the complexities of transporting and cleaning the hot solid stream and the aluminum recovery. Further research on the NAAS process is recommended.

Biodegradation and Resource Recovery Systems

Composting is perhaps the most proven technology of any of the energy/resource recovery systems analyzed in this report. Unfortunately, composting plants have been the least successful, with only one or two plants currently still in operation. Composting offers moderate volume reduction, and may be a feasible solid waste disposal method for smaller communities, but it does not appear to be a viable method for large municipalities.

Methane recovery from solid waste in existing landfills is currently possible, and the possibility exists for future methane recovery from specially designed sanitary landfills. The latter method is unproven and involves long-range planning. Biochemical processes are feasible now for disposal of certain industrial wastes, but the application to refuse disposal is still in the conceptional and research stages.

Resource recovery systems, similar to the Black-Clawson process or the front-end systems of a number of energy recovery processes, involve proven technology for recovery of magnetic materials and glass. Recovery of nonmagnetic metals, especially aluminum, and color-sorted glass involve advanced technology, which has not demonstrated on a large-scale commercial basis. Any community interested in resource recovery must always be cognizant of the markets for the recycled materials.

SELECTED REFERENCES

3- 1 Jeffers, E. L.; and Nuss, R. H.: Solid Waste as an Energy Source. Rpt. D2-118534-1, Boeing Aerospace Company, February 4, 1974.

3- 2 Resource Recovery--The State of Technology. Midwest Research Institute Report. (NTIS No. PB 214 149), February 1973.

3- 3 Solid Waste Shredding Growing in Importance. Waste Age Magazine, May/June 1974, pp. 30-36.

3- 4 Seven Year Experiment. Solid Waste Management, Feb., 1974, pp. 16-58.

3- 5 Rof, J. A.: Refuse Shredders. Waste Age Magazine, May/June 1974, pp. 58-66.

3- 6 Hammermill, Inc.: Refuse Applications Calculations. May 8, 1972.

3- 7 Allis-Chalmers: Refuse Shredder Specifications. Model KH 12/18, Bulletin 3355371.

3- 8 Drobny, N. L.; Hull, H. E.; and Testin, R. F.: Recovery and Utilization of Municipal Solid Waste. Report SW-10C, Battelle Memorial Institute, Columbus Laboratories, 1971. (EPA PH 86-67-265), Columbus Laboratories, 1971.

3- 9 Stearns, R. P.; and Davis, R. H.: The Economics of Separate Refuse Collection. Waste Age, May/June 1974, pp. 6-15.

3-10 Materials Recovery System--An Engineering Feasibility Study. National Center for Resource Recovery, Inc., Washington, D. C., December 1972.

3-11 Boettcher, R. A.: Air Classification of Solid Wastes. Publication SW-30C, Stanford Research Institute, Irvine, California, 1972. (Federal Solid Waste Management Program PH 86-68-157).

3-12 Brison, R. J.; and Tangel, O. F.: Development of a Thermoadhesive Method for Dry Separation of Minerals. Mining Engineering. Aug. 1960, pp. 913-917.

3-13 Bleimeister, W. C.; and Brison, R. J.: Benefaction Application of the Gravitational Inertial Classifier. Mining Engineering. Aug. 1960, pp. 918-921.

3-14 Rydor, R. J.; and Abrahams, J. H., Jr.: Separation of Glass from Municipal Refuse. Paper presented at Solid Waste Resource Conference, by Battelle Memorial Institute, Columbus, Ohio; May 13, 1971.

3-15 Morey, B.; and Rudy, S.: Aluminum Recovery From Municipal Trash by Linear Induction Motors. 103rd Annual Meeting of American Institute of Mining, Metallurgical and Petroleum Engineers, Dallas, Texas, Feb. 24-28, 1974.

3-16 Cummings, J. P.: Glass Recovery From Municipal Trash by Froth Flotation. Proceedings of the Third Mineral Waste Utilization Symposium, Chicago, Illinois, March 14-16, 1972.

3-17 Solid Waste Resource Recovery Plant. Bulletin by Combustion Equipment Associates, Inc., and Arthur D. Little, Inc.

3-18 Bauer, H. F., et. al.: Technical Report on the Garrett Pyrolysis Process for Recycling Municipal Solid Waste. (EPA grant rpt: PL91-512) Garrett Research and Development Corporation Report No. 72-022 A & B, Dec. 1972.

3-19 Stump, P. L.: Solid Waste Demonstration Projects. EPA SW-4p, 1972.

3-20 U. S. Environmental Protection Agency: Second Report to Congress; Resource Recovery and Source Reduction, Publication SW-122, 1974.

3-21 Schulz, H. W.; Neamatalla, M.; Tong, G.; and Young, M.: Pollution-Free System for the Economic Utilization of Municipal Solid Waste for the City of New York. Phase I - A Critical Assessment of Advanced Technology, Columbia University, June 15, 1973.

3-22 Jackson, F. R.: Energy from Solid Waste. Noyes Data Corp., Park Ridge, N. J., (1974).

3-23 Leatham, H., Jr.: A "Powerful" Solution to the Solid Waste Problem. Bulletin by Commonwealth Associates, Inc., Jackson, Michigan.

3-24 Astrom, L.; Kranebitter, F.; Strandell, O.; and Harris, D. W.: A Comparative Study of European and North American Steam Producing Incinerators. Proceedings of the 1974 National Incinerator Conference, May 12-15, pp. 255-266.

3-25 Roberts, R. M.; Sommerlad, R. E.; and Konopka, A. P.; et. al.: Systems Evaluation of Refuse as a Low Sulphur Fuel, Vol. II. EPA Contract No. CPA 22-69-22. NTIS Report PB 209-272 November, 1971.

3-26 Massey, D.; Kelly, W. E.; Landis, E. K.; and McKinley, M. D.: Urban Refuse Incinerator Design and Operation: State of the Art. U. S. Bureau of Mines (BER Report No. 133-119), Bureau of Engineering Research, University of Alabama, June 1971.

3-27 White, H. J.: Industrial Electrostatic Precipitation. Addison Wesely Publishing Co., Reading, Mass., 1963.

3-28 Resource Recovery Processes for Mixed Municipal Solid Wastes - Part II - Catalogue of Processes, Midwest Research Institute Final Report - Project 3634D, December, 1972.

3-29 Pepperman, C. M.: The Harrisburg Incinerator: A System Approach. Proceedings of the 1974 National Incinerator Conference, May 12-15, pp. 247-253.

3-30 Wilson, M. J.: A Chronology of the Nashville, Tennessee Incinerator with Heat Recovery and the Compatible Central Heating and Cooling Facility. Proceedings of the 1974 National Incinerator Conference, May 12-15, pp. 213-221.

3-31 Chapman, R. S.; and Wocasek, F. R.: CPU-400 Solid-Waste-Fired Gas Turbine Development. Proceedings of the 1974 National Incinerator Conference, May 1974, pp. 347-357.

3-32 Horner and Shifrin, Inc.: Solid Waste as Fuel for Power Plants. NTIS Report No. PB-220 316, 1973.

3-33 Generation of Steam from Solid Wastes, Metcalf and Eddy, Inc., EPA Report PB-214 166, 1972.

3-34 Standrod, S. E., Jr.: The RESCO North Shore Facility. Presented at the U. S./Japan Energy Conservation Seminar, sponsored by the Southwest Research Institute, San Antonio, Texas, Feb. 1974.

3-35 Bulletin, Combustion Power Company, Inc., 1346 Willow Road, Menlo Park, California, 1972.

3-36 Bulletin: The CPU-400 Pilot Plant. Combustion Power Company, Inc., 1346 Willow Road, Menlo Park, California, December, 1972.

3-37 Bobco, D. L.: Proposed Analysis of Economic and Environmental Feasibility of Utilizing Reclamated Solid Waste as a Fuel Source for Production of Electricity. Report M71-31, The Mitre Corporation, June, 1971.

3-38 Vaughan, D. A.; Miller, P. D.; and Boyd, W. K.: Fireside Corrosion in Municipal Incinerators versus PVC Content of the Refuse. Proceedings of 1974 National Incinerator Conference, May, 1974, pp. 179-189.

3-39 Fernandes, J. H.; and Shenk, R. C.: The Place of Incineration in Resource Recovery of Solid Waste. Proceedings of the 1974 National Incinerator Conference, Miami, Florida; May 12-15, 1974, pp. 1-10.

3-40 Aubin, H.: The New Quebec Metro Incinerator. Proceedings of the 1974 National Incinerator Conference, Miami, Florida; May 12-15, 1974, p. 205.

3-41 Sutterfield, G. W.: Refuse as a Supplementary Fuel for Power Plants. Interim EPA Progress Report, Nov., 1973 to March, 1974, July, 1974.

3-42 Steel Products News Bureau. American Iron and Steel Institute Bulletin, New York; March 8, 1973.

3-43 Low, Robert A.: Energy Recovery from Waste-Solid Waste as Supplementary Fuel in Power Plant Boilers. EPA Report SW-36d. ii, 1973.

3-44 Winners Named for Construction and Operation of $80,000,000 Resource Recovery Plants in Connecticut. Resource Recovery, Apr./May/June, 1974, pp. 8-9.

3-45 Burton, R. S.; and Bailie, R. C.: Fluid Bed Pyrolysis of Solid Waste Materials. Combustion, Feb. 1974, pp. 13-18.

3-46 Aldrich, D. C.: Kinetics of Cellulose Pyrolysis. PhD Dissertation. MIT, Feb. 1974.

3-47 "OSWMP/PDD Issue Paper - Pyrolysis of Solid Waste" Office of Solid Management Program, Environmental Protection Agency, July 1972.

3-48 "A Proposed Plan of Solid Waste Management for Connecticut," prepared by General Electric, 1973.

3-49 Anderson, J. E.: The Oxygen Refuse Converter - A System for Producing Fuel Gas, Oil, Molten Metal and Slag from Refuse. Proceedings of the ASME 1974 National Incinerator Conference, pp. 337-346.

3-50 Finney, C. S.; and Garrett, D.E.: The Flash Pyrolysis of Solid Wastes. 66th Annual AIChE Meeting Philadelphia, Pa., Nov. 1973. (Garrett Research and Development Corporation Rpt. No. 73-021).

3-51 Mallan, G. M.; and Finney, C. S.: New Techniques in the Pyrolysis of Solid Wastes. 73rd Nat'l AIChE Meeting, Minneapolis, Aug, 1972. (Garrett Research and Development Corporation Report No. 72-035).

3-52 Stola, J.; and Chatterjee, K.: An Advanced Process for the Thermal Reduction of Solid Waste. Contained in "Solid Waste Demonstration Projects -- Proc. of a Symposium," EPA Publ. SW-4p, 1972, pp. 109-127.

3-53 Knight, J. A.; Tatom, J. W.; Bowen, M. D.; Colcord, A. R.; and Elston, L. W.: Pyrolytic Conversion of Agricultural Wastes to Fuels. Presented at the Annual Meeting of the American Society of Agricultural Engineers, Stillwater, Oklahoma, June 1974.

3-54 Hammond, V. L.; et al: Energy from Forest Residuals by Gasification of Wood Wastes. Pulp & Paper, February, 1974.

3-55 Hammond, V. L.: Pyrolysis-Incineration Process for Solid Waste Disposal. Final Report, Battelle Northwest Laboratories, Grant No. 1, G06-EC-00329 (EPA), December, 1972.

3-56 Pyrolysis Study of Fuel from Solid Waste. Preliminary Document by Barber-Colman against NASA Contract Number NAS 914305, Aug. 1, 1974.

3-57 Solid Waste: Most of It Still Goes to the Dump. Engineering News Record, Nov. 22, 1973, pp. 22-25.

3-58 Solids Recycling Takes Shape in Twin Cities. Engineering News Record, March 21, 1974, pp. 51-52.

3-59 Storck, W. J.: Sludge is Beautiful in the Twin Cities. Water & Wastes Engineering, July 1974, pp. 43-45.

3-60 Linaweaver, F. P.: Baltimore Tries Pyrolysis. The American City, May, 1974.

3-61 Bielski, E. T.; and Ellenberger, A. C. J.: Landgard for Solid Waste. Proceedings of the 1974 National Incinerator Conference, Miami, May 1974, pp. 331-336.

3-62 Landgard System for Resource Recovery and Solid Waste Disposal. Monsanto Enviro-Chem Systems, Inc., Bulletin, March, 1974.

3-63 Boegly, W. J. et al: MIUS Technology Evaluation - Solid Wastes. ORNL-HUD-MIUS-9 Report, Oak Ridge National Laboratory, Jan. 1973, p. 70.

3-64 Wilson, D. G., ed.: The Treatment and Management of Urban Solid Waste. Technomic Publishing Co., Inc., Westport, Conn., 1972, p. 140.

3-65 Bailie, R. C.; and Ishida, M.: Gasification of Solid Waste Materials in Fluidized Beds. Chemical Engineering Applications in Solid Waste Treatment, AIChE Symposium Series 122, Vol. 68, 1972, pp. 73-80.

3-66 Bailie, R. C.; and Burton, R. S., III: Fluid Bed Reactors in Solid Waste Treatment. Chemical Engineering Applications in Solid Waste Treatment, AIChE Symposium Series 122, Vol. 68, 1972, pp. 140-151.

3-67 Bailie, R. C.: High Energy Gas from Refuse Using Fluidized Beds. West Virginia Univ., Final Report to EPA on Grant 5-R01-EC-00399-03-EUH, Aug. 1972.

3-68 Pyrolysis of Solid Waste: A Technical and Economic Assessment. Stanford Research Institute Report for West Virginia University, Sept. 1972.

3-69 Sterba, J. D.: Garbage Pile Turned to Fuel. Washington (D.C.) Star-News, page A-3, Saturday, Nov. 24, 1973.

3-70 Pyrolysis - Production of Gaseous Fuel from Solid Waste. A technical proposal submitted to NASA, JSC, in response to request for Proposal 9-BC731-38-4-86P, by Arthur D. Little, Inc. and Combustion Equipment Associates, Inc., April, 1974.

3-71 Hammond, V. L.; and Mudge, L. K.: Feasibility Study of Use of Molten Salt Technology for Pyrolysis of Solid Waste. Final Report, Contract No. 68-03-0145, Battelle Northwest Laboratories for EPA, April, 1974.

3-72 Nichols Herreshoff Multiple Hearth Furnaces. Bulletin No. 233, Nichols Engineering and Research Corp., New York.

3-73 Sanner, W. S. et al.: Conversion of Municipal and Industrial Refuse into Useful Materials by Pyrolysis. Bureau of Mines Report No. 7428 (1970).

3-74 Schlesinger, M. D., et al.: Pyrolysis of Waste Materials from Urban & Rural Sources. Proceedings of the Third Mineral Waste Utilization Symposium, Chicago, March 1972.

3-75 Feldmann, H. F.: Pipeline Gas from Solid Wastes. AIChE Symposium Series G8 (122), 1972, pp. 125-131.

3-76 Kaiser, E. R.; and Friedman, S. B.: The Pyrolysis of Refuse Components. Combustion, May, 1968, pp. 31-36.

3-77 Rosen, B. H.; Evans, R. G.; Carabelli, P.; and Zaborowski, R. B.: Economic Evaluation of a Commercial Site Refuse Pyrolysis Plant. Proceedings of National Industrial Solid Wastes Management Conference, University of Houston, May 1970, pp. 393-406.

3-78 Lessing, L.: The Salt of the Earth Joins the War on Pollution. Fortune, July 1973, pp. 138-147.

3-79 McFarland, J. M., et al.: Comprehensive Studies of Solid Wastes Management. Final Report, UCB-Eng-2907, USPHS 2RO 1 EC 00260-05, SERL Rpt. No. 72-3, May 1972.

3-80 Ricci, L.: Garbage Routes to Methane. Chemical Engineering, May 27, 1974, pp. 58-60.

3-81 Pyrolysis - Production of a Gaseous Fuel from Solid Waste, Vol. I. A Technical Proposal submitted to NASA, JSC in response to request for Proposal 9-BC731-38-4-86P by Hamilton Standard, NASA Contract No. NAS-9-14306, April, 1974.

3-82 Solid Waste Disposal Plans for Monroe County. Vol. I, II, III. Rochester Engineering Society, Rochester, New York, April, 1972.

3-83 Garrett, D. E.; and Sass, A. S., assignors to Occidental Petroleum Corp., U. S. Patent No. 3,698,882, Oct. 17, 1972. Continuous Phase for the Conversion of Carbonaceous Solids into Pipeline gas.

3-84 Oxygen Plant Will Produce Fuel Oil From Refuse. Oil and Gas Journal, March 19, 1973.

3-85 VanHorn, K. R., ed.: Aluminum Fabrication and Finishing. Vol. III. American Society of Metals, Metals Park, Ohio, p. 3.

3-86 Cronch, C. N.; and Sleppy, W. C.: Oxidation of High Purity Aluminum and 5052 Al-Mg Alloy at Elevated Temperature. J. of Electro. Chem. Soc., Vol. 108, 1961, pp. 322-327.

3-87 Zanoni, A. E.: Potential for Ground Water Pollution from the Land Disposal of Solid Wastes. CRC Critical Reviews in Environmental Control, Vol. 3, No. 3, May 1973, pp. 225-260.

3-88 Golueke, C. G.; Card, B. J.; and McGauhey, P. H.: A Critical Evaluation of Inocutums in Composting. Applied Microbiology, Vol. 2, No. 1, January 1954, pp. 45-53.

3-89 Wiley, J. S.; and Kochtitzky, O. W.: Composting Developments in the United States. Compost Science, Vol. 6, No. 2, Summer 1965, pp. 5-9.

3-90 Breidenbach, A. W., Director; Staff of the Federal Solid Waste Management Research Office, Environmental Protection Agency: Composting of Municipal Solid Wastes in the United States. EPA SW-47r, G. P. O., 1971.

3-91 Sanders, F. A.; and Bloodgood, D. E.: The Effect of Nitrogen-to-Carbon Ratio on Anaerobic Decomposition. Journal of the Water Pollution Control Federation, Vol. 37, No. 12, December 1965, pp. 1741-1752.

3-92 Glysson, E. A. et al.: The Problem of Solid-Waste Disposal. College of Engineering, University of Michigan, Ann Arbor, Michigan, 1972.

3-93 Pfeffer, J. T.; Leiter, M.; and Worlund, J. R.: Population Dynamics in Anaerobic Digestion. Journal of the Water Pollution Control Federation, Vol. 39, No. 8, August 1967, pp. 1305-1322.

3-94 Dogue, R. R.; McKinney, R. E.; and Pfeffer, J. T.: Solids Retention in Anaerobic Waste Treatment Systems. Journal of the Water Pollution Control Federation, Vol. 42, No. 2, Part 2, February 1970, pp. R29-R46.

3-95 Pfeffer, J. T.: Reclamation of Energy from Organic Refuse. (Grant No. EPA-R-800776) Department of Civil Engineering, University of Illinois, April 1973.

3-96 Singh, R. B.: Bio-Gas Plant, Generating Methane from Organic Wastes. Gobar Gas Research Station, Ajitmal, Etawah (V. P.) India, 1971.

3-97 Fry, L. J.; and Merrill, R.: Methane Digesters for Fuel Gas and Fertilizer. The New Alchemy Institute-West, Santa Barbara, California, 1973.

3-98 Gobar Gas; Methane Power in India. The Mother Earth News, No. 12, November 1971, pp. 28-31.

3-99 Mother's Methane Maker; A test unit designed by Ram Bux Singh. The Mother Earth News, No. 18, November 1972, pp. 12-13.

3-100 The Plowboy Interview; Ram Bux Singh. The Mother Earth News, No. 18, November 1972, pp. 6-11.

3-101 The Plowboy Interview; L. John Fry. The Mother Earth News, No. 23, September 1973, pp. 6-12.

3-102 Wise, D. L., et al.: Fuel Gas Production from Solid Waste. Report No. 1151, NSF Contract C-827, Dynatech Corp., Cambridge, Mass., January 1974.

3-103 Brunner, D. R.; and Keller, D. J.: Sanitary Landfill Design and Operation. EPA SW-65ts, G.P.O., 1972.

3-104 Meller, F. H.: Conversion of Organic Solid Wastes Into Yeast; an Economic Evaluation. H. E. W.--P. H. S. Publication No. 1909, G.P.O., 1969.

3-105 Rogers, C. J.; Coleman, E.; Spino, D. F.; and Purcell, T. C.: Production of Fungal Protein from Cellulose and Waste Cellulosics. Environmental Science and Technology, Vol. 6, No. 8, August 1972, pp. 715-718.

3-106 Callihan, C. D.; and Dunlap, C. E.: Construction of a Chemical-Microbial Pilot Plant for Production of Single-Cell Protein from Cellulosic Wastes. Contract No. PH 86-68-152, Department of Chemical Engineering, Louisiana State University, EPA SW-24c, G.P.O., 1971.

3-107 Reese, E. T.: A Microbiological Process Report, Enzymatic Hydrolysis of Cellulose. Applied Microbiology, Vol. 4, No Number, 1956, pp. 39-45.

3-108 Brandt, D.; Hontz, L.; and Mandels, M.: Engineering Aspects of the Enzymatic Conversion of Waste Cellulose to Glucose. AIChE Symposium Series, Vol. 69, No. 133, pp. 127-133.

3-109 Reese, E. T.; Mandels, M.; and Weiss, A. H.: Cellulose as a Novel Energy Source. Advances in Biochemical Engineering, Volume 2 (Springer-Verlag, 1972), pp. 181-200.

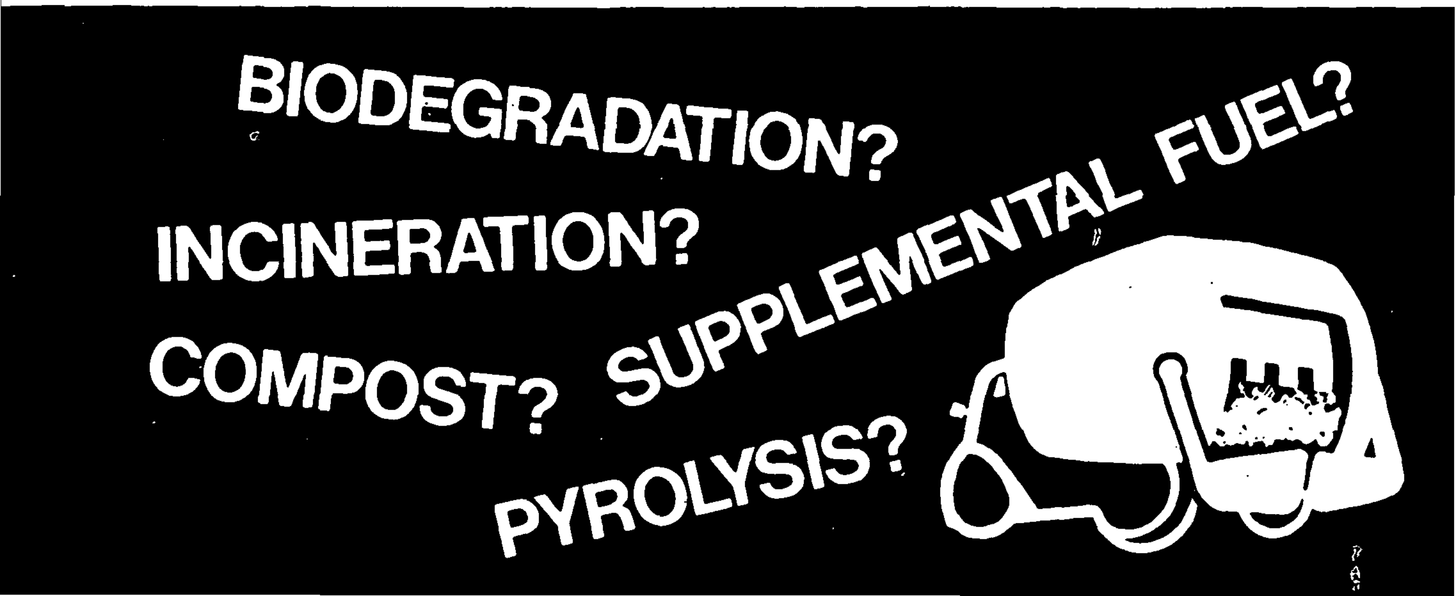
3-110 Hagerty, D. J.; Pavoni, J. L.; and Heer, J. E., Jr.: Solid Waste Management. Van Nostrand Reinhold Company, 1973.

3-111 Golueke, C. G.: Critical Review of the Literature on Solid Waste Management. CRC Critical Reviews in Environmental Control, Vol. 3, No. 3, May 1973, pp. 261-301.

3-112 McGauhey, P. H.: American Composting Concepts. EPA SW-2r, G.P.O., 1971.

Chapter 4
Markets

ENERGY RECOVERY FROM SOLID WASTE



4.1 INTRODUCTION

Since market considerations are the primary determinants of the economic viability of energy and resource recovery systems, it is imperative that a community carefully negotiate the sale of process outputs. In a discussion of secondary material markets, Darnay (ref. 4-1) states:

> "An axiom in the salvage industry is that "scrap is not sold, it is bought." The skilled secondary materials dealer is a skilled buyer. Because he sells a substitute for raw materials, he cannot control his selling price. It is determined by demand, which in turn is influenced by availability and cost of virgin resources.
>
> Demand and price fluctuate; the dealer sometimes may be forced to tap every conceivable source to satisfy demand. At other times, he must "turn off" his poorer sources. If necessary, he will buy from his best sources to protect them during periods when demand is low, in order to retain them as sources when demand is again high.
>
> The successful dealer keeps his inventories low, buying at the appropriate price. He avoids long-range commitments to buy (especially from poor sources) and to sell (unless the sales price is negotiated high enough or is pegged just above a published market price). The skilled dealer "rides the market", buying only what he can sell, selling everything he buys, and keeping a safe margin between his buying and selling prices."

As noted in Chapter 3, process outputs are very dissimilar and it is not enough to be assured that all output products can be sold. Demand and price fluctuate, and daily changes can be noted in the secondary material markets. A fact finding group may evaluate the cost of a disposal system based on a current price of $17/metric ton for recovered ferrous metal, only to discover that the price has dropped to $5/metric ton by the time the plant is built and on line. The extreme fluctuation in the price of recycled newspaper is another good example of the uncertainty which must be considered when trying to estimate credits in the economics analysis. Finding product markets and negotiating guaranteed prices may be the key to keeping incineration and pyrolysis costs within acceptable limits.

This chapter examines the products of energy and resource recovery systems and focuses on the economic value, marketing problems, and future prospects for these products.

4.2 MARKETABLE PRODUCTS

It is difficult to imagine that <u>all</u> components of a solid waste disposal system can be effectively utilized. It is, however, an ideal goal and this section will list some of the products that result from the solid waste stream including material recovered during pre-and post processing. It is recognized that some products and byproducts cannot be used in their present state, but additional processing might make them marketable. This of course, is dependent upon technical and economic considerations.

4.2.1 Material Recovered before Conversion

The following list of products is representative of those that can be reclaimed prior to any conversion:

- ferrous metals
- glass
- paper products (newsprint, cardboard)
- plastics
- nonferrous metals (aluminum, zinc, lead, copper)

4.2.2 Products Derived from Conversion Processes

These are the most common products resulting from incineration or pyrolysis. These appear in varying amounts and qualities depending on the process, and include:

- fuel gas
- fuel oil
- solid fuel
- char
- methane
- power
- electric
- steam

4.2.3 Conversion Byproducts

Ideally, there would be no pollutants and no residue to be landfilled after the solid waste had been processed. Currently research is being conducted to see if byproducts can be used in construction materials or soil conditioners. Typical of conversion byproducts are:

- frit
- fiber and humus
- fly ash
- CO_2
- compost
- slag, glass stone, dirt
- residue

4.3 FACTORS RELATED TO CURRENT MARKET CONDITIONS

As discussed in Chapter 2, there are a number of Federal laws and regulations or policies that discourage the sale of energy and resources recovered from municipal solid waste. While such policies do not prohibit such sales they do give advantages to the use of virgin resources and thus discourage the use of products manufactured from secondary materials. Examples of these policies are freight rates for secondary materials, depletion allowances and rules of capital amortization, and federal policies fixing the price of natural gas.

Certain practices by a segment of the public sector cause local fluctuations in market prices and demand. For example, paper drives by church or civic groups can saturate a local used-paper buyer to the extent that regular used-paper suppliers have little or no immediate market. Even if the market still exists, the price could have been driven so low by the "paper-drive" that the regular used-paper suppliers operate at a loss.

4.3.1 FREIGHT RATE POLICIES

While it is not currently possible to demonstrate that the higher freight rates cause an actual decrease in the amount of secondary materials recycled, it can be demonstrated that certain secondary materials cost more to ship than virgin materials. A 1974 publication (ref. 4-2) of the EPA discusses the problem and presents the following conclusions:

1. Freight rates are higher for some secondary materials such as rail rates for scrap iron, glass cullet, reclaimed rubber and ocean rates for wastepaper.

2. Freight rates represent a substantial fraction of the cost of using many secondary materials.

3. While there is some potential for discrimination, there is no direct evidence to indicate that higher freight rates result in a reduction of recycling.

4. Further study is needed to determine the extent to which there is discrimination against secondary materials.

4.3.2 FEDERAL TAX POLICIES FOR VIRGIN MATERIALS

Several Federal tax policies give benefits to industries engaged in the recovery of virgin materials. At the present time, such Federal tax policies apply only to recovery of natural or virgin resources and not to the same material recovered from secondary sources.

The EPA in its Second Report to Congress estimated the total tax benefits from preferential treatment in the areas of depletion allowances, capital gains tax treatment, expensing of capital improvements for tax purposes, and foreign tax allowances. These estimates are displayed below in Table 4-1 and are discussed in Chapter 2.

TABLE 4-1
SUMMARY OF ESTIMATE OF TAX BENEFITS, 1970

Product	Unit Value	Total Value (millions of dollars)
Paper	\$0.899 per kg (short ton)	35.75
Petroleum	\$0.350 per 0.159 m^3 (barrel)	1,350.00
Natural gas	\$0.022 per 28.3 m^3 (10^3 ft^3)	450.00
Iron ore	\$0.748 per 1016 kg (long ton)	96.64
Coal	\$0.142 per 1016 kg (long ton)	80.59
Bauxite (used for aluminum)	\$1.496 per 1016 kg (long ton)	20.96
Sand (used for glass)	\$0.082 per 1016 kg (long ton)	0.86

Source: EPA Second Report to Congress (ref. 4-2) p.33

These estimates point out the competitive advantage enjoyed by the virgin materials industries.

4.3.3 FEDERAL POLICIES REGULATING NATURAL GAS

The Federal Power commission regulates the transportation of natural gas in interstate commerce as well as the sale in interstate commerce of natural gas for resale for ultimate public consumption for domestic, commercial, industrial or any other use, and natural gas companies engaged in such transportation or sale (ref. 43). Thus, if a pyrolysis plant produced a gas which was to an electrical generating system which comes under the jurisdiction of the FPC, that pyrolysis plant might also be subject to FPC regulations and be forced to price its gas at an artifically low price. (ref. 4-4). This would naturally reduce the financial attractiveness of energy recovery through pyrolysis.

Even if the pyrolysis plant were not under FPC jurisdiction, it could be forced to sell its gas at a low price in order to compete with natural gas priced according to FPC regulations. For a number of years the FPC has set the price of natural gas shipped into interstate commerce at 32¢/10^9 joules (34¢ per million BTU's). Recently, this price was raised to 43¢/10^9 joules (46¢ per million BTU's) on new production. Pyrolysis gas might be priced above the FPC ceiling and remain competitive. This is because demand for interstate natural gas exceeds available supplies. Many industries may accept a higher priced pyrolysis gas in place of the lower priced, but unavailable, natural gas. An additional competitive advantage of pyrolysis gas is the possibility of contractually guaranteed supply. If a shortage of natural gas occurs, FPC policy requires utilities to give priority to residential customers and service to industrial customers may be curtailed. Pyrolysis gas, as an interstate commodity, is not subject to this constraint.

4.3.4 Federal Procurement Policies

One of the largest problems to overcome in recycling is that of market uncertainty. Since the Federal Government is the single largest consumer of many products it has been suggested that Federal procurement of recycled materials could be used to establish a stable market for products manufactured from secondary materials. This has been done with paper products and automobile and truck tires. The EPA has concluded, however, that while the Federal government is the single largest consumer of many products it does not constitute, by itself, a sufficient demand to create a stable market for recycled materials. State and local governments and other consumers must join the Federal government in the effort to create a market for recovered resources. (ref. 4-2).

4.3.5 Social Attitudes

The social attitudes of consumers also have a great influence on the marketability of recovered resources. These attitudes, which are discussed in detail in Chapter 2, are briefly summarized here. The first of these is reluctance of consumers to undertake separation of disposable items at the household level. If source separation were practiced, front end systems would be unnecessary, and resource recovery would be much less expensive. Second, consumers tend to avoid purchasing products made from nonvirgin material. A prime example of this is the reluctance to use table napkins made from recycled paper taken from garbage.

4.4 Products Suitable for Current Markets

Resource recovery is recognized as an important aspect of solid waste management and the recovery process can be structured so that resources can be recovered before, during, or after the actual processing of the solid waste. The nature of the products recovered is dependent on the stage in the process at which recovery takes place. Table 3-3 shows the typical composition of MMR but it should be noted that many of these materials cannot be marketed without some type of processing. Many products which are immediately saleable are recovered before processing.

4.4.1 Product Description

Although approximately a quarter of the tonnage of paper, major metals, glass, textiles and rubber consumed in recent years in the U. S. has been acquired through recycling operations, most of it has been salvaged from manufacturers and businesses, where large amounts of relatively clean and homogeneous wastes accumulate. Very little is currently being salvaged from municipal refuse (ref. 4-5).

The technical feasibility of recovering various materials from the municipal waste stream has been well demonstrated in the past even though the reclamation of salvage material becomes more difficult when it is mixed with garbage and other refuse. According to the EPA, (ref. 4-6)

> "---had currently-known technology been applied in 1972 to residential and commercial solid wastes in metropolitan areas, almost 14 million tons of steel, aluminum and glass could potentially have been recovered and substituted for their virgin material counterparts".

4.4.1.1 FERROUS METALS

Ferrous metals account for roughly 7 percent of the municipal waste stream. After the large bulky items have been removed and after the rest of the incoming refuse has been shredded, the ferrous metal is usually extracted magenetically.

It is estimated that 60 to 80 percent of the recoverable ferrous metals is in the form of steel cans which are, in reality, a composite of tin-plated steel and possibly lead, organic coatings and aluminum. The composite can fraction contains approximately 92 percent steel, 0.4 percent tin, 1.5 percent lead, 3.7 percent aluminum and 1.8 percent organic coatings. It is these nonferrous residuals that often make "can scrap" a "bad scrap". (ref. 4-7).

4.4.1.2 PAPER

Paper, the largest single component of municipal waste, is one of the most important manufactured materials in the United States. Paper products can be classified into three broad categories; paper, paperboard, and construction paper.

Waste paper, which can be used as a raw material in the same way as wood pulp, is classified as either bulk or high grades. Bulk grades are used in sizeable quantities in paperboard and construction products. High grades are high quality fibers which can be directly substituted for woodpulp. About 80 percent of recycled waste paper falls into one of three bulk grades:

1. news: old newspapers recovered in residences
2. corrugated: old corruguated boxes discarded in commercial establishments
3. mixed: unsorted papers of the lowest quality which is generated in office buildup and printing plants.

High grade wastepaper is of two types; pulp substitute and de-inked. Pulp substitute consists of high quality fibers derived from paper-converting plants and tab cards from data-processing centers. De-inked wastepaper is usually bleached paper recovered in printing plants.

Two factors enter recovery of paper and paper products. First, approximately seven-eights of all paper products can be recovered. Examples of unrecoverables are library materials and tissue products in sewage systems. Second, recycled paper is not as good as new after recycling. Each time that paper goes through a recycle, its fibers become shorter and more frayed. The result is a product that has lesser use than the virgin product. Even if strength is not a factor, color of the recycled paper could influence its use. Slick magazines yield as much ink and clay as recovered fibers in a recycling process. The disposal problems of recycling can also be a problem.

4.4.1.3 GLASS

Glass makes up about 10 percent by weight of municipal solid refuse. Glass scrap, which is called cullet, is a desirable input material for the glass industry because it liquefies at a lower temperature than the other raw materials. The use of cullet in the glass industry has the effect of reducing fuel consumption and air pollution emissions, and it helps to extend the life of furnance linings. Thus, the use of glass cullet can be economically advantageous and could reduce costs $2 to $3 per metric ton of input (ref. 4-1).

Technology currently exists for extracting and color-sorting glass from municipal solid waste but it is not yet in large scale use. As part of a larger demonstration project in Franklin, Ohio, the EPA is investigating the feasibility of recovering glass as a byproduct from an aluminum recovery system. Preliminary results from this project indicate that the expected economics of the joint recovery of aluminum and glass is attractive, even after considering the additional investment for color-sorting the recovered glass (ref. 4-1).

4.4.1.4 PLASTICS, RUBBER and OTHERS

Plastic is one of the most difficult materials to extract from municipal solid waste, and no plastic recovery now takes place from municipal solid waste. The heat content of plastics approximates that of coal, and consequently plastics have great heating value in energy recovery systems. Unfortunately, burning plastics in the presence of moisture produces hydrochloric acid vapors. These vapors are very corrosive and pose an equipment maintenance problem as well as an air pollution problem.

Most of the rubber in mixed municipal refuse is either in the form of tires or such products as soles and heels on footwear. Reclamation of rubber from mixed refuse appears impractical at this time, especially because of the technical limitations in its recovery. For a more extensive discussion of problems and prospects for plastics and rubber tires, see the discussion in Chapter 2.

4.4.1.5 FUEL OIL and GAS

One of the most common products resulting from a pyrolysis process is fuel oil. The major marketing obstacle is the reluctance of the petrochemical industry to use gases or liquids produced by a waste-disposal system as a feedstock. Discussions with representatives of the petrochemical industry indicate that privately owned chemical companies are not interested because of impurities and fluctuation in chemical composition.

Since there has not yet been a major attempt to produce and market these products, this judgement is conjectural. It is also worth noting that even if this conjecture is correct, it does not rule out the sale of combustible liquids or gases to chemical companies for use as a fuel.

Table 4-2 shows a comparison of gases from two different processes and Table 3-30 gives a comparison of no. 6 fuel oil and typical pyrolytic oil.

TABLE 4-2
GASEOUS FUEL ANALYSIS

Gas	Monsanto	Garrett
Nitrogen	69.3%	--
Carbon Dioxide	11.4%	27.0%
Carbon Monoxide	6.6%	42.0%
Hydrogen	6.6%	10.5%
Methane	2.8%	5.9%
Oxygen	1.6%	--
Ethylene	1.7%	--
Ethane	--	4.5%
C_3 to C_7 Hydrocarbons	--	8.9%

4.4.2 MARKET DEMAND

As noted earlier, viable markets and market prices hold the economic key to the future of many of the suggested processes. Darnay (ref. 4-1) observes:

> The product quality of the resource recovery systems is dependent upon the components of the municipal waste input, and usually the products compete in the low-quality end of the markets for which they are suitable. This is a key factor that must be considered in looking at economic viability of recovery process. However, each product of the resource recovery processes has a unique relationship to its potential market considering its quality. For example, electricity can be a relatively valuable energy product in some situations but has very marginal commercial values in others.
>
> Materials recovered for recycling are often relatively valuable but only IF a market exists for the grade and quality of product derived from the recovery system.

This section examines the demand and discusses source causes for low demand for some of the specific products.

4.4.2.1 TIN CANS

The three principal markets for salvaged tin cans are: the detinning industry, the steel industry and the copper precipitation industry; the detinning industry could be considered an intermediate processor since it extracts the tin from the cans and sells the ferrous scrap to the steel industry. The largest use of recovered cans today is for precipitation iron in the copper precipitation industry. As mentioned earlier, cans usually do not meet the quality scrap requirements in either the detinning and steel industry. There are also constraints on the use of tin cans in the precipitation process; the most important are:

1. the increasing aluminum content of the cans, which causes problems in the precipitation process, and
2. the high shipping costs usually required, since the mines are located in Arizona, Utah, Montana, Nevada and New Mexico.

The demand for iron in the copper precipitation industry is expected to double over the next 15 years but this market is judged by the EPA to be of limited overall importance. (ref. 4-7). Less than 4 percent of the copper ore in the U. S. is refined by the type of process which uses precipitation iron.

The market for salvaged cans in the detinning industry has been limited by problems caused by contaminants, primarily aluminum. Although aluminum could be removed by further processing, this would increase costs and would make aluminum removal uneconomical for the detinning industry. The detinning industry is not a large one and currently processes a neglible quantity of salvaged cans; more of these cans could be absorbed by the present demand were they available from municipalities.

Steelmaking is yet another potential use for tin cans. The greatest difficulty with the use of tin cans in steelmaking is their tin, aluminum and lead residuals; these contaminants can cause damage to the refractory lining of the meling furnace. With the advent of electric furnaces in the steel industry, greater quantities of recycled cans will be used because of the electric furnaces' capability of producing steel from a charge of 98 percent scrap. Detinned steel scrap can be used in steelmaking since the detinning process removes contaminants and improves the quality of the steel.

4.4.2.2 PAPER

Table 4-3 illustrates how wastepaper was utilized in 1970 in the manufacture of paper. Approximately 40 percent of the paper recycled today is acquired from paper converters while about 60 percent is recovered from residential and commercial sources. As might be expected, corrugated and mixed bulk comes mostly from commercial sources with residences providing over 80 percent of the news or bulk waste paper grade (ref. 4-1).

Although there are some mechanical processing systems capable of recovering wastepaper from mixed municipal refuse, very little paper recovery takes place using such systems. These systems are still undergoing tests and require further development before they can be practically used.

Even though wastepaper recycling of old newspapers, corrugated paper and office paper was 6.7 million metric tons in 1970 (ref. 4-7) it is estimated that recycling of these bulk grades could be greatly improved, especially within the large urban centers as indicated in Table 4-4.

Recovery of paper stock from mixed municipal refuse is currently practiced to a small extent, and is mostly done by hand sorting at the processing plant. It is estimated that between 1/2 to 3/4 metric tons per hour can be hand sorted by one man; thus separation time is on the order of 1.3 to 2 man-hours per metric ton (ref. 4-11).

Wastepaper is generally marketed through paper brokers. As shown in section 4.4.3, the prices that brokers are willing to pay vary greatly in both geographical location and time.

4.4.2.3 GLASS

Table 4-5 shows how the use of nonreturnable glass containers has increased in recent years. This has a very significant effect on the amount of glass that eventually will find its way to the solid-waste stream. Even with this significant increase in production, Table 4-6 shows that cullet consumption has been very slight.

There are several constraints on the use of cullet in the glass industry which could help explain the low fraction of purchased cullet in the above table.

1. Cullet must be clean and free of metallic contaminants, especially aluminum and iron.

2. Cullet must be crushed into pieces of size 1 inch or

TABLE 4-3
WASTEPAPER UTILIZATION IN PAPER AND PAPERBOARD

Type of paper	Total U.S. paper production	Total wastepaper consumption	Type of waste consumed: Mixed paper	Newspaper	Corrugated paper	Pulp substitutes and high-grade deinked paper
Total for all grades and molded pulp (10^3 tons)	53,329	12,021	2,639	2,238	4,080	3,067
Total paper (10^3 tons):	23,409	2,228	33	455	108	1,632
Newsprint	3,345	371	--	371	--	--
Printing, writing, and related	11,023	736	--	--	--	736
Tissue	3,595	971	7	76	69	819
Other	5,446	150	26	8	39	77
Total paperboard (10^3 tons):	25,465	8,330	1,766	1,473	3,779	1,312
Unbleached kraft and solid bleached	15,036	285	48	8	162	67
Semichemical	3,460	754	42	28	622	62
Combination	6,969	7,291	1,676	1,437	2,995	1,183
Construction paper and board, molded pulp, and other (10^3 tons):	4,455	1,463	840	307	193	123
Distribution (percent)	--	100.0	22.0	18.6	33.9	25.5

TABLE 4-4
WASTEPAPER AVAILABILITY (RECOVERABLE GRADES, 1970)

Type of paper	Paper (10^3 tons) Consumed	Discarded to waste stream	Recovered	Generated in SMSA's	Recoverable: Maximum (75 percent of that generated in SMSA's	Recoverable: Minimum (30 percent of that generated in SMSA's	Additional increment recoverable
Newspaper	9.8	9.7	2.2 (22.4 percent)	7.4	5.5	3.7	1.5- 3.3
Corrugated	13.3	13.2	2.6 (20.0 percent)	10.0	7.5	5.0	2.4- 4.9
Mixed and high grade (primary office papers)	11.1	9.1	2.6 (23.6 percent)	8.3	6.2	4.2	1.6- 3.6
Total	34.2	32.0	7.4	25.7	19.2	12.9	5.5-11.8

smaller, and must be color sorted (flint, amber, or green).

Although residential waste glass is fairly clean, it is often contaminated and mixed with other waste thus making it more difficult to recover; this plus the fact that it must be color sorted severely inhibits the recycled glass market.

Summarizing, then, clean and color-sorted scrap glass is a valuable and desirable raw material for the glass industry, and because of the potential demand for this type of cullet, it is a marketable product. At present, though, the available recovery technology for glass from solid waste is not sufficiently developed to make recovery of clean and color-sorted glass economically desirable.

4.4.2.4 ALUMINUM

Most large aluminum companies in this country are now involved in aluminum can recycling, and have sponsored a number of aluminum recycling centers and recovery programs. These recovery programs have been mostly based on voluntary citizen collection and delivery to a specific site. Although there is, as of this moment, no well developed process for reclaiming aluminum from the municipal waste, the EPA is investigating (in the EPA-sponsored Franklin, Ohio project) an aluminum recovery system which has not yet been fully demonstrated.

The establishment of many can-reclamation centers throughout the country, coupled with the high prices currently being paid for this metal scrap explains why aluminum recovery is being considered in most of the recovery systems currently under development. Scrap processors in this country still handled approximately 70 percent of the aluminum scrap sold in 1970 (ref. 4-12).

4.4.3 MARKET PRICES

Prices which can be obtained for most secondary products are extremely variable. Since the production of garbage is a large continuous and on-going process, the solid-waste disposal industry cannot respond quickly enough, nor store its commodity long enough to take advantage of optimum price levels. Without government support, it must make guaranteed long-term contracts to stay competitive. Current market prices are discussed with respect to specific products.

4.4.3.1 PAPER PRODUCTS

Prices for wastepaper are very time and location dependent. Wastepaper prices fluctuate widely and operating in this market requires skill and knowledge of the

TABLE 4-5
BEER AND SOFT DRINK FILLINGS AND CONTAINER CONSUMPTION, 1967-1970 IN MILLION UNITS
(Ref. 4-1)

	1967	1968	1969	1970
Soft drink:				
Glass closures	32,715	31,046	36,133	35,349
Metal cans	7,290	10,028	11,764	12,856
Glass container shipments:				
Returnable	1,913	1,747	1,640	1,603
Nonreturnable	3,586	4,644	6,457	8,360
Total fillings	40,005	41,074	47,897	48,205
Market share %:				
Metal cans	18.2	24.4	24.5	26.6
Returnable bottles§	72.8	64.3	62.0	56.1
Nonreturnable bottles	9.0	11.3	13.5	17.3
Avg. no. trips, returnable bottles	16	15	14	n.a.
Beer:				
Glass closures	17,003	16,092	17,834	17,747
Metal cans	13,769	15,342	16,708	18,864
Glass container shipments:				
Returnable bottles	624	475	480	350
Nonreturnable	5,784	5,985	6,876	7,248
Total fillings	30,772	31,434	34,542	36,611
Market share%:				
Metal cans	44.7	48.8	48.4	51.5
Returnable bottles	36.5	32.2	31.7	28.7
Nonreturnable bottles	18.8	19.0	19.9	19.8
Avg. no. trips, returnable bottles	19	20	20	n.a.

TABLE 4-6
GLASS PRODUCTION AND PURCHASED CULLET CONSUMPTION, 1967

(See Ref. 4-1)

Industry segment	Production in 1,000 tons	Purchased cullet consumption in 1,000 tons	Purchased cullet, percent
Containers	8,950	100	1.1
Flat glass	2,150	244	11.3
Pressed and blown	1,720	256	14.9
Total	12,820	600	4.7

relationships between demand, prices and inventories. In 1967 in New York, for example, clean bulk newsprint commanded prices of $16-$17 per metric ton ($15-$16 per ton) (ref. 4-11), while the same item in Los Angeles, five years later, was $14 per metric ton ($13 per ton), and $30 per metric ton ($27 per ton) in the Philadelphia area. The 1972 average U. S. price for clean bulk newsprint was on the order of $22 per metric ton ($20 per ton). Prices for clean newsprint in 1974 in the Houston area have been on the order of $33-$44 per metric ton ($30-$40 per ton) although in recent months prices have dropped to $4.4 per metric ton ($4 per ton). In fact, at this market low (in Houston), purchases of any kind were only from those suppliers who had established themselves as dependable future sources. Minimum guaranteed prices of about $27 per metric ton ($25 per ton) have been reported in the west coast area in long term contracts. Current cardboard prices in the Houston area are in the range of $22-$33 per metric ton ($20-$30 per ton).

4.4.3.2 GLASS

The basic raw materials for the manufacturing of glass containers cost between $16 and $20 per metric ton of glass produced. Since the substitution of cullet saves processing plants $2 - $3 per metric ton of input, cullet can sell for $18 - $23 per metric ton and still be competitive with virgin raw materials (ref. 4-12). According to Anchor Hocking in Houston, the current price paid for clean, color-sorted glass in this area is about $20 per metric ton.

As in the case of all secondary products, the economics of glass recovery from solid waste is very much dependent on the proximity of the markets. The prices quoted earlier are net prices at the site, and thus transportation costs must also be taken into account when considering the economics of glass recovery.

4.4.3.3

Since most recoverable aluminum from solid waste is in the form of cans, it is reasonable to use the prices paid at voluntary redemption centers as the price for aluminum scrap; in 1972 this price was $181 per metric ton (ref. 4-12). In August, 1974, aluminum reclamation centers in Houston were paying 33¢/kilogram (30¢/pound) for aluminum cans, or $272 per metric ton - fob at the reclamation center. This gives some indication of how time dependent these prices can be. However, aluminum prices are expected to continue rising and additional credits may be realized from the sale of aluminum recovered from municipal waste.

4.4.3.4 GAS AND FUEL OIL

Another contributing factor to the large price variations is the difference in composition of recovered products that the different processes produce. For example, gas compositions vary in attractiveness to potential customers (see Table 4-2).

Typical natural gas prices for various locations are present in Table 4-7.

TABLE 4-7
VARIATION OF NATURAL GAS PRICES

Location	$/2.83 x $10^3 m^3$ ($/1,000 ft^3)*
Houston	$ .25
Denver	.29
Minneapolis	.46
Seattle	.44
Washington, D.C.	1.06
New York	.87

*1000 cu. ft. contains approximately 10^6 Btu

These prices have increased substantially in recent months.

As of August, 1974, the price in Houston has risen to $.32/$10^9$ Joules ($.34/$10^6$ Btu) while the price in the northeastern part of the country, specifically Connecticut, has risen to $2.12/$10^9$ Joules ($2.40/$10^6$ Btu).[1]

Purchasers will have to assess the suitability of the pyrolysis oil to arrive at a price they are willing to pay. In the case of the Garrett oil, one of the main considerations is the high viscosity of the oil. It is anticipated that prices for this oil may range from 2¢ per liter ($3.00 per barrel) to a possible high of 6¢ per liter ($10.00 per barrel) in special situations.

4.4.3.5 FERROUS METAL

The copper precipitation industry pays

[1]Telephone conversation with Ken Rodgers of Combustion Equipment Associates, August 6, 1974.

the highest price for ferrous metals, on the order of $50 to $65 per 907 kilogram ($50 to $65 per ton) at the mine with a maximum of $75 per 907 kilogram ($75 per ton) (ref. 4-11). This high price is explained by the fact that the demand is far from the large urban centers which are the places where "production" of the ferrous metal scrap is concentrated. Most of the mines are located in various points in Arizona, Montana, Nevada, and Utah. Freight charges from urban areas to these places are quite high, and this accounts for an important part of the total cost of the scrap metal at the mine.

Recovered ferrous cans which cannot be economically transported to copper mines may find a market as No. 2 bundle scrap (ref. 4-12), or as a feedstock to the detinning industry. According to Iron Age, the composite average price paid in 1972 for No. 2 bundles in Pittsburgh, Chicago, and Philadelphia was $25.46 per 907 kilogram ($25.46 per ton) (ref. 4-14). The detinning industry paid, in 1967, an average of $21.59 per 907 kilogram ($21.59 per ton) for tin plated scrap delivered at their plants (ref. 4-1).

4.5 POTENTIALLY PROMISING MARKETS

In addition to industrial demand, other factors play a role in secondary material markets. The secondary materials industry is inadequately capitalized and poorly organized. An influx of new capital technology, and managerial skills is needed to improve the productivity of the secondary materials industry.

As discussed in Chapter 2, many federal tax and transportation rate policies work to the disadvantage of secondary material dealers. Changes in these policies are long overdue, and would have an important revitalizing influence on the entire industry. Finally, procurement policies at all levels of government which give preferential treatment to products utilizing secondary materials would help to stabilize secondary materials markets and promote resource recovery. These factors should facilitate a more positive cycle where stable demand encourages the kind of investment in resource recovery which will ensure a stable supply of secondary material. The general availability of supplies of secondary materials will in turn encourage new industrial utilization of these resources.

As implied many times in this report, most products are of marginal economic value but much can be done to improve this situation. Some specific examples are given below.

Various potential markets for specific chemicals exist. The ability to take advantage of some of these markets will depend on the need of local industries. Other markets, however, are tied to the needs of the municipalities. The use of CO_2 in the tertiary treatment of sewage is a good example of municipal usage.

A fuel derived from MMR may be utilized by electric utilities which can either use the fuel directly or use steam generated at the disposal plant. The possibility of supplying steam to a district heating network also exists. An important consideration when selling steam is the distance the steam must be piped. Low energy content can place severe limitations on this distance.

A major impediment to the direct marketing of the fuel gases produced by many pyrolysis processes is their low Btu content. In the case of the liquid fuel produced by the Garrett process, a major drawback is its high viscosity and potentially corrosive nature which can greatly increase its handling expense.

A potential market for the carbon char produced by pyrolysis disposal is in waste water treatment, where it can be substituted for commercial activated carbon. With respect to the vitrious frit which is frequently a pyrolysis residue, the most promising market appears to be in the production of asphalt.

4.6 MARKETS TO BE DEVELOPED

There are two basic approaches to marketing products:

(1) try to capture a share of exisiting markets from similar type products, or.

(2) create a need for an available product where none currently exists.

The gas and oils produced from the pyrolytic process, for instance, are products which must compete for a share of the energy market. On the other hand, research conducted at the University of Missouri at Rolla indicates that a market might be developed for recycled glass in the production of glasphalt.

There are numerous marketing problems to be solved in both methods if a successful solution is expected in the solid waste handling problem.

4.6.1 RESEARCH AND DEVELOPMENT

Research is needed to help in making

and marketing products that result from solid waste systems. Some possibilities are briefly discussed below.

Research on recycled glass has already been mentioned and some of the more promising secondary products which use scrap glass are slurry seal street paving (ref. 4-15), glasphalt (ref. 4-16), bricks (ref. 4-17), insulated wall panels (ref. 4-18), glass rubble building panels, glass wool, terrazzo type flooring (ref. 4-19), foamed glass building materials (ref. 4-20), ceramic building tiles (ref. 4-21), cement and concrete (ref. 4-22).

One manufacturer has developed a process for making high tolerance bricks which can use almost any reasonable aggregate, including glass recovered before or after an energy conversion process, frit, residue, slag stone and residue dirt (ref. 4-23). These bricks are more costly to make, but since they are high tolerance, the added manufacturing cost is more than offset by labor saving in laying the bricks. They can be laid with a glue rather than mortar. This takes less labor, less time, less skill, and it creates a stronger wall because the mortar, which is the weakest part of a brick wall, is replaced by a stronger adhesive.

Insulated wall panels and glass rubble building panels might use from 13 - 94 percent reclaimed glass and demolition rubble including scrap brick and stone. Mineral wool insulation now uses up to one percent reclaimed glass. This could be increased to about 50 percent to make a glass wool insulation.

It is possible to make terrazzo type flooring using reclaimed glass rather than marble chips and research is being conducted in this area.

Finally, research on scrap plastics (refs. 4-24, 4-25, 4-26), fibers and humus recovered from solid waste may develop saleable products which can be made from materials recovered from solid waste.

4.7 TRENDS AND DEVELOPMENTS

Before discussing what the future holds for markets and utilization, let us first note the conditions and events responsible for our present situation. Up to the present, solid waste disposal has consisted of either open dumping, sanitary landfilling, or crude incineration. The primary virtue of these disposal methods is their apparent low cost.

Until recently, laws have been quite flexible as to the pollution levels permitted in dumping, incineration, and sanitary landfills. As a result, the cost of these alternatives remained low. Land for dumps and landfills has been easily available, and the cost of transporting refuse to these locations has not been excessive compared to the cost of available alternatives. With the enormous growth of urban centers however, new disposal sites have become difficult to find. Land costs have increased and available sites are more distant from the waste source. This has been compounded by increased transportation costs. To control the costs of traditional disposal methods certain reforms have been implemented. An example is the creation of transfer stations in many large urban centers. More important, however, is the fact that rising costs have forced local governments to search for new solutions to the waste-disposal problem.

Public pressure to alleviate some of the environmental liabilities of current methods of solid waste disposal has forced research in new methods. Governmental agencies at all levels have also become increasingly aware of the negative environmental aspects of incineration, open dumping, and sanitary landfilling. All of this has resulted in new laws and increased pressure for government to seek better solutions to the problem of waste disposal.

In summary, alternatives to dumping and incineration were not considered in the past because:

1. Land for disposal sites was cheap and easy to find.
2. Transportation distances for hauling refuse to incineration, open dumps or landfills were relatively short.
3. There was little pressure from the public for legislative regulation to pollution and environmental quality.

This situation has changed and we now find ourselves with a variety of new approaches to the solid-waste disposal problem. These are in various stages of development, testing and implementation. At present many private companies are trying to sell municipal waste conversion systems to cities. The economic success of most of these conversion systems depends on the sale of a mix of products, byproducts and energy. The success of most of the conversion systems available in the market today will also be affected by any future legislative restrictions.

4.7.1 Some Recent Trends

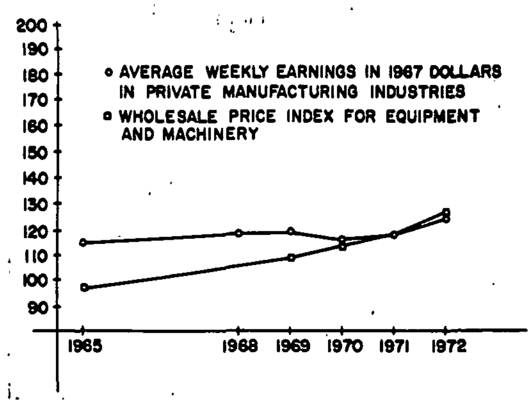
Previous sections of this report have

shown approximate net costs per metric ton for various conversion processes. In locations where landfilling or incineration are very economical as well as feasible, some of the new conversion processes may not compete favorably. There are areas however, where, due to local, state or Federal laws, the traditional approaches are not feasible, and other areas where they may be feasible but extremely costly. In these instances it may be less expensive to use one of the processes discussed in Chapter 3. These processes have not yet received wide acceptance because the anticipated revenue from the sale of recovered energy and materials is not sufficient to make the net cost per metric ton competitive with existing disposal methods. This picture is changing rapidly for two reasons:

1. The market for most energy products and recyclable materials is becoming more attractive, and

2. Laws and policies by local, state and Federal governments are making energy and resource recovery more attractive.

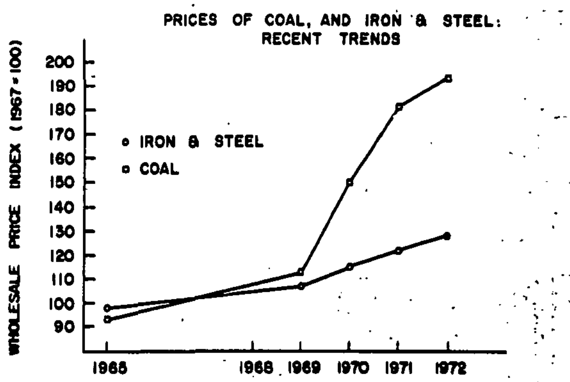
While it is true that most commodity and service prices are increasing, not all are increasing at the same rate. For example, labor and equipment both constitute a major fraction of the capital and operating costs of almost all energy and resource recovery systems. Figure 4-1 shows how the costs of equipment and labor have been recently changing. As seen in Figure 4-1, costs for labor and equipment are increasing; costs of equipment and machinery, however, have shown a greater increase than labor costs.



SOURCE: STATISTICAL ABSTRACTS OF THE U.S., 1973

FIGURE 4-1
COSTS OF LABOR AND EQUIPMENT; RECENT TRENDS

Most, if not all, of the conversion processes currently available have net costs per metric ton which are very sensitive to the credits received from energy production and recovered materials. There is no doubt, after looking at Figures 4-1 and 4-2 (both with the same scale) that the coal and iron price curves in Figure 4-2 have much steeper slopes than equipment and labor cost curves in Figure 4-1. The price of coal has been recently increasing at an extremely rapid rate. All available evidence indicates that the prices of most fuels will be increasing sharply in the years ahead.



* SOURCE: STATISTICAL ABSTRACT OF THE U.S., 1973

FIGURE 4-2
PRICES OF COAL, AND IRON AND STEEL; RECENT TRENDS

It was pointed out in Chapter 3 that of all conversion processes studied in this report, the supplementary fuel method seems to hold the greatest promise since it is highly competitive with all known and existing waste disposal methods. In the supplementary fuel process, the net cost per ton is highly sensitive to the credit received by burning prepared refuse as fuel. In most cases the value per million BTU of prepared refuse will approximate that of coal.

If the prices of coal, iron and steel, together with those of labor and equipment continue changing according to a pattern similar to that of recent years, many refuse conversion processes will become competitive with landfill and other traditional disposal approaches.

Other important developments will also encourage the recycling of secondary materials and the recovery of energy from solid waste; this will in turn make their markets much more attractive than what they are at present. The more important of these developments are:

1. National policy, as expressed in the Solid Waste Disposal Act of 1965, is to encourage recycling and to promote the effective "utilization" of solid waste.

2. Pending legislation points to more and better use of the available resources in the municipal waste stream.

3. Costs of traditional waste disposal approaches will continue to increase sharply.

4. New technology will improve the feasibility of recovering energy and materials from municipal solid waste.

5. Research and development is creating new products which can be made from materials recovered from solid waste.

4.7.2 CONTRACT AGREEMENTS

Long-term contracts are an integral part of solid-waste disposal systems. Since all of the processes are capital intensive, long-term contracts are essential, not only to keep the operation economical, but in order to obtain financing as well. Of course, long-term contracts can be detrimental if they are not carefully negotiated. Resource Recovery, Inc. in Houston has a 20 year contract to sell scrap metal for $20/ton. It is likely that if this same contract were negotiated today a price of $30/ton could be obtained. With increasing scarcity of resources, this upward trend is likely to continue.

The classic example of a need to find adequate markets and secure contracts is the Chicago Northwest Incinerator. It currently produces steam, but the steam is not used, and, therefore no revenue credits can be taken for this energy. At present, the steam is condensed and dumped into Lake Michigan.

At the other end of the spectrum, the Baltimore Gas & Electric Co. has agreed to buy all the steam produced by the Baltimore Landgard system. Furthermore, under the terms of the contract, the price received increases as the price of oil goes up. This arrangement has proven beneficial to buyer and seller alike.

A possible limitation is the restriction of the contractual powers of municipalities. As discussed in Chapter 2, many cities have restrictions in their charters setting a limit on the maximum number of years the city can contractually bind itself; 5 years is a common limit.

4.7.3 MARKET LOCATIONS

The economic viability of incineration or pyrolysis is dependent upon the availability of local markets. Since many of the outputs from municipal solid-waste systems are of low quality, they are only marginally attractive, even when transportation distances are small. When markets are distant, the economic benefits disappear because the transportation costs begin to override any possible monetary gain.

4.8 CONCLUSION

At the present time there is no reliable market for many products produced from solid waste (ref. 4-27). However, future developments may lead to improved markets for such products. For example, energy prices have increased in the past few years and substantial evidence exists to indicate that they will continue to increase as the world demand for energy increases. Research and development for new products utilizing solid waste materials is presently being conducted and encouraged by Federal government grants. Proposed legislation in the form of the Hazardous Waste Disposal Act (ref. 2-28) and increasing landfill costs may make landfills impossible in many cities. This should encourage trends toward energy and resource recovery. Additional legislative proposals are being formulated to study the effects of federal policies such as freight rate and tax incentives for virgin materials on the secondary materials markets. If legislation is forthcoming to provide tax incentives for secondary materials recovery, this should encourage the development of markets. Legislation on air standards for incinerators is closing this option for many cities and encouraging resource recovery systems.

The following suggestions concerning markets are made to any municipality considering an energy and resource recovery plant.

1. Location of the plant should be close to the energy product use, and, if possible, close to purchasers of other recovered materials.

2. Location of the energy conversion plant should also be related to the MMR source to minimize transportation charges for collection.

3. Long-term estimates should be made concerning local markets for as many as

possible of the materials to be recovered. Long-term contracts are often possible.

4. Larger municipal areas might investigate the possibility of encouraging the manufacturing of products which utilize materials recovered from solid waste. This would help create markets for the recycled materials.

5. Municipalities should consider themselves as a potential market for the energy and secondary resources recovered from MMR.

SELECTED REFERENCES

4- 1 Darnay, Arsen; and Franklin, Wilham E.; Salvage markets for materials in solid wastes; Report prepared for the Environmental Protection Agency, Solid Waste Management Program by Midwest Research Institute, Report SW-29c, 1972.

4- 2 Staff of Environmental Protection Agency: Second Report to Congress, Resource Recovery and Source Reduction. (SW-122), Washington, D.C., 1974.

4- 3 Section 1(b), Natural Gas Act, 1938, as amended.

4- 4 FPC vs Florida Power & Light Co. 404 U. S. 453, Jan. 12, 1972.

4- 5 Solid Waste Management Series Publication, U. S. Environmental Protection Agency: Recycling and the Consumer, Report #SW-117, 1974.

4- 6 Lowe, Robert A.: Energy Conversion Through Improved Solid Waste Management, Report SW-36d. ii, U. S. Environmental Protection Agency, 1973.

4- 7 Solid Waste Management Publication, U. S. Environmental Protection Agency: Second Report to Congress, Resource Recovery and Source Reduction, Report #SW-122, 1974.

4- 8 Supplied by Mr. E. A. Stewart, Manager, Landyard Systems, Monsanto Enviro-Chem Systems, Inc., St. Louis, Missouri.

4- 9 New Techniques in the Pyrolysis of Solid Wastes by G. Mallan & C. Finney of Garrett Research & Development Co., Paper presented to American Institute of Chemical Engineers, 73rd National Meeting, August 1972.

4-10 New Techniques in the Pyrolysis of Solid Wastes by G. Mallan & C. Finney presented to American Institute of Chemical Engineers 73rd National Meeting, August, 1972.

4-11 Drobny, N. L.; Hall, H. E.; and Teskin, R. F.: Recovery and Utilization of Municipal Solid Waste, Report SW-10c prepared for the Environmental Protection Agency Solid Waste Management Office by Battelle Memorial Institute, Columbus Laboratories, 1971.

4-12 Materials Recovery Systems: An Engineering Feasibility Study by the National Center for Resource Recovery, Inc., Washington, D.C. December 1972.

4-13 Solid Waste as an Energy Source, Report No. D2-118534-1 by Boeing Aerospace Co., Houston, Texas, February 1974.

4-14 Iron Age, January 4, 1973, Volume 211.

4-15 Road to Future Paved with Garbage. Machine Design, Vol. 43, November 1971, p. 40.

4-16 Unrefined Waste Glass Seen O.K. for Glasphalt. Publication Works, Vol. 104, January 1973, p. 104.

4-17 Anon.: Bricks from Recycled Wastes Used in Home Construction. American Concrete Institute Journal, Vol. 69, August 1972, p. 14.

4-18 Anon.: The Commercial Potentials of Glass Wool Insulation. The National Research Institute; published by The Glass Container Manufacturers Institute, Inc., Washington D.C.

4-19 Anon: The Commercial Potential of Terrazzo with Glass Aggregate. The Midwest Research Institute; published by The Glass Container Manufacturers Institute, Inc., Washington D.C.

4-20 Anon: The Commercial Potential of Foamed Glass Construction Materials made with Waste Glass and Animal Excreta. The Midwest Research Institute; published by The Glass Container Manufacturers Institute, Inc., Washington, D.C.

4-21 Anon: The Commercial Potential of Ceramic Tile made with Waste Glass and Animal Excreta. The Midwest Research Institute; published by The Glass Container Manufacturers Institute, Inc., Washington, D.C.

4-22 W. Gutt: Aggregates from Waste Materials, Chemistry and Industry, June 3, 1972, pp. 439-447.

4-23 Anon: New Process Turns Wastes into Bricks, Chemical and Engineering News, Vol. 49, September 13, 1971, pp. 49-50.

4-24 B. Baum; and C. H. Parker: "Future of Plastic Disposal," Society of Petroleum Engineers Journal, Vol. 29, May 1973, pp. 41-45.

4-25 D. R. Paul; and others: "Potential for Refuse of Plastics Recovered from Solid Wastes," Polymer Engineering & Science, Vol. 12, May 1972, pp. 157-166.

4-26 Japan 1971: Coping With a Downturn, Plastics, Vol. 49, January 1972, pp. 66-68.

4-27 Arsen Darnay: "Recycling Assessment and Prospects for Success," U. S. Environmental Protection Agency, 1972.

4-28 U. S. Environmental Protection Agency, "Report to Congress, Disposal of Hazardous Wastes," (SW-115), Washington, D. C., 1974.

Chapter 5
A Decision Procedure

ENERGY RECOVERY FROM SOLID WASTE

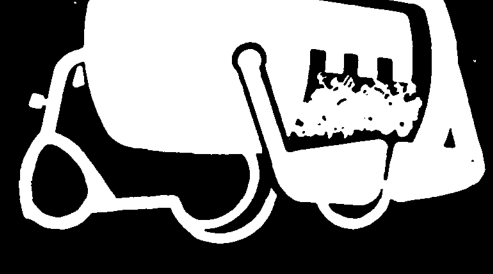
BIODEGRADATION?

INCINERATION?

COMPOST?

SUPPLEMENTAL FUEL?

PYROLYSIS?



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5.1 INTRODUCTION TO DECISION PROCEDURE

5.1.1 JUSTIFICATION

A brief examination of the history of solid-waste disposal practices illustrates the need for an interdisciplinary approach to decision making in this area.

Until the 1960's, most communities, using only a least cost criterion for waste disposal, practiced open dumping. About 80-85 percent of the country's waste went into unsanitary open dumps (Glysson, ref. 5-1). Enough people, environmentally concerned in the 1960's, encouraged legislation prohibiting open dumps. Examples of such laws are Michigan Public Law 87 (1965) and the Texas Refuse Dumping Law (1963). Federal policy promoting the closing of open dumps, i.e., Mission 5000 in the 1960's, also motivated better land disposal methods-sanitary landfills.

Many communities then turned to either incineration to reduce the amount of residue going to a landfill or used the sanitary landfill alone. However, as soon as the incinerators were built many were shut down because they could not economically meet particulate and gaseous emission standards set forth in the Federal Clean Air Act of 1965.

In the late 1960's, then, communities were faced with not only economic but also environmental and legal constraints when deciding where to dispose of municipal waste.

Also, to compound the difficulty for municipal officials there arose problems with sanitary landfills. These problems were not economic or environmental but social and political in nature. As local areas sought more landfill sites people nearby protested. When officials of Monroe County, New York, sought places to landfill the garbage of Rochester, no other town in the county would accept the waste (Glysson, ref. 5-1, Cross, ref. 5-2). Cases of this problem can be found almost daily in local newspapers. For example, citizens of Limestone County, Texas, prevented very recently the location of an industrial landfill in their area (ref. 5-3).

Another example of landfill problems is the controversy between the city of Grand Rapids, Michigan and Kent County (ref. 5-4). The dispute is over who should pay transportation costs which exceeded contract figures when the city's refuse was trucked to a county landfill. This is a political and legal problem.

Political and social acceptability must then be added to economic and environmental concerns in order to make successful solid waste disposal decisions.

Yet another consideration must be accounted for, however. This is the problem of markets. Many cities, dissatisfied with landfills and incineration turned to composting as a socially and environmentally acceptable alternative. In 1972, 18 plants were reported in the United States (Glysson, ref. 5-1). However, only two were reported operating at that time. When the compost market disappeared, most of the operations were no longer economically viable.

The conclusion from this brief historical sketch is that regions still concerned with cost must now integrate into their decision process social, political, environmetal, legal, and market considerations.

There is evidence today that communities are becoming aware of the need for an interdisciplinary approach to solid waste decision making.

Along these lines, a rather unique seminar was held for consulting engineers in Buffalo, New York, during June, 1974. The following quote is from the introductory address by Gordon Eastwood who is responsible for Solid Waste Management Programs in New York State. It illustrates the growing sensitivity of public officials to the need for broad input into solid waste disposal decisions.

> " . . . we will address such issues as market, legal, administrative, financing, contractual, site location, municipal vs. private ownership, economics, feed stock guarantees, legislative and others which hinder implementation of resource recovery programs. The consulting engineer has worked closely with municipalities and their agents in planning and implementing many environmental programs. This effort should continue. However, present approaches to solid waste management strongly suggest that these firms evaluate their resource recovery staffing to consider and include other talents than the professional engineer." (ref. 5-5)

5.1.2 PHILOSOPHY

Many communities have considered the difficult history of incineration, landfill, and composting solutions, and are moving toward solutions which maximize resource and energy recovery - the focus of this report. A study of the Rochester, New York, waste disposal problem by a volunteer group from the Rochester Engineering Society contains the following quote:

> "The Environmental Management Council believes that there is only one long range solution that is environmentally acceptable and that solution is based upon recycling.

Landfill is not an acceptable long-range solution . . . " (ref. 5-6)

This approach is now being implemented in Monroe County after an extensive market survey related to end use of recovered materials including refuse fuel for a local utility boiler (ref. 5-7). The basic point is that any solution considering resource or energy recovery must consider viable markets.

Along with market data a full analysis must be made of the local social and political climate. Good planning will hopefully avoid citizen and institutional resistance to solutions.

The philosophy of the following decision process is simply that the decision maker must consider markets and social data and only then consider technical options for compatibility. (This does not imply that social and market data cannot be reconsidered in light of the subsequent technical option analysis.) The tendency in the past has been to take a current technical option and try to "shoehorn" it into the community. In short, the technical options for solid waste disposal should fit the community not vice versa.

5.1.3 Outline of Procedure

The following sections give in detail the steps of the proposed decision process to be carried out by local officials or their agents. A brief introductory outline is given here.

A schematic outline of the process is given in Figure 5-1. (A more detailed diagram is Figure 5-2 in section 5.4.)

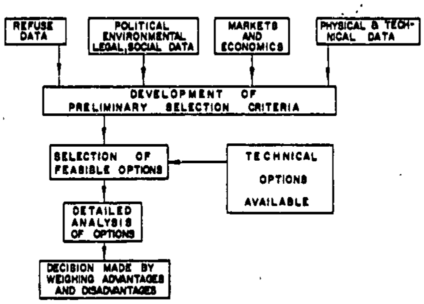

FIGURE 5-1
BLOCK DIAGRAM OF DECISION PROCESS

The four blocks across the top emphasize the data collection areas related to waste disposal in a community. Refuse amounts, location of waste generators, political institutions, social culture, economic bases, laws, geology, weather and many others must be determined (see section 5.2). From these data, decision criteria for that particular community are developed. These criteria are then put together as preliminary selection criteria to screen all technical options available. This process should yield options feasible for the community. For example, a locale that decides to allow no emissions, however benign, into the air will eliminate from detailed consideration any such processes that produce emissions. As another example, the absence of a fiber board market may eliminate other processes in the early screening phase.

This preliminary screening process reduces the number of technical options to those compatible with the community. These in turn are evaluated in more detail. Economic analyses and desirability evaluation techniques are then used to see which option of those feasible best fits the needs of the community.

This information is then given to the final decision makers - a city council, county commission, waste disposal authority or legislature for their use in making a final selection.

The procedure given below is designed to help local officials account for all the important dimensions of the solid waste problem in making successful decisions. The process is an attempt to integrate material in previous chapters relating to social data, technical options, and market information into a procedure useful to local communities.

5.2 DEVELOPMENT OF SELECTION CRITERIA

5.2.1 Introduction

This section presents first of all a discussion of the more important factors to be considered by decision makers when deciding upon a local disposal method. The discussion ends with an outline of factors for the convenience of the reader. These factors may be used in the preliminary screening process (section 5.3) and in the more detailed analysis of the systems still under consideration after the screening process (section 5.4).

5.2.2 Economic and Cost Related Characteristics

The following is a discussion of characteristics which relate to economics directly or indirectly. These characteristics can be used in forming selection criteria.

5.2.2.1 CAPITAL COST

An estimate of capital cost including equipment, land and working capital gives an idea of which systems might be compatible with the financing potential of a community. Usually, higher capital costs mean more desirable features. This is an important tradeoff to be considered in the selection process.

5.2.2.2 FLEXIBILITY

Systems have different amounts and types of flexibility. Most of these systems are built for twenty year periods. The need for flexibility or ease of alteration could be due to a number of variable factors. Capacity needs might change in the future. Composition of MMR might change. Laws concerning the environment and recovered products may change. The value of the energy products and recycled materials may change. Political structures and social attitudes might change. Technical developments, not known today, may be so beneficial in the future as to warrant equipment alterations. As population centers shift the location of the system may need changing.

5.2.2.3 RELIABILITY AND MAINTAINABILITY

Corrosion, abrasion, high temperatures, and normal wear and tear lead to breakdowns which in turn leaves the MMR unprocessed. Ease of repairing the system and the availability of parts and service seem all important at such times. A short repair time is important. Built in redundancy could help by saving the system from a complete halt. Some systems may have more MMR storage capabilities than others. A landfill "next door" is often recommended to accomodate the refuse if breakdowns occur.

5.2.2.4 STANDARDS

Local pollution control standards, EPA standards, public health regulations and OSHA safety standards must be met by any system considered. Future standards and the legal information in Chapter 2 should be considered.

5.2.2.5 CONSTRUCTION AND START-UP TIME

Design, installation and start-up time intervals need to be considered in light of when the system is needed.

In many areas, disposal problems are in the crisis stage. Monroe County in New York has run out of landfill sites and needs to install a new system right away. Even so, the projected start-up date for a resource recovery system is 1977 (ref. 5-7). In contrast, the Houston, Texas area has enough landfill sites for the near future. Here the start-up time for a new system is not critical. Houston can afford to let technology develop more while Monroe County cannot.

5.2.2.6 MAINTENANCE COSTS

The cost of maintaining equipment, buildings, and grounds should be considered. Preventive maintenance programs, the number of employees and degree of personnel training required for maintenance should be considered. The cost of "down time" is also important.

5.2.2.7 OPERATING COSTS

Operating costs are maintenance overhead, direct labor and materials, utilities, taxes, insurance, interest, disposal of residue, fringe benefits, fuel, administration, plus miscellaneous expenses. These are not unrelated to qualitative factors; for example, the use of more employees than necessary may be a political decision or the demand by the community culture to recycle may result in more maintenance. Further, managing many small units rather than one large unit might be offset by savings in transportation of refuse to the operation. On the other hand, economies of scale might be more important. Possibilities of modular planning should be considered. If modules are added when more capacity is needed, the original cost is lower and capital cost is expended as needed. Also, higher labor costs could be offset by better equipment reliability and good employee training. The possibility of strikes and unionization should be taken into account. Difficulty of operation, and vulnerability to misuse or mishandling would be less important with more expensive skilled labor.

The relationships between these various qualitative factors and costs should be carefully considered. A good understanding of the tradeoffs involved will result in good decisions.

5.2.2.8 SALE OF RECOVERED RESOURCES

The type of resources recovered, the form in which they are recovered, the availability of markets, the effect on the market prices of the added resources supplied, the reliability demanded by potential customers, the reliability expected from the conversion process, the possibility of creating new markets, transportation possibilities including traffic conditions, roads, access to rail spurs, all affect the estimates of present and expected future credits from the sale of resources recovered and energy products manufactured.

Prices incorporated into long term contracts would possibly be lower than prices quoted in present markets. Long term contracts could be demanded by those financing the proposed system. Even without this demand, the security of long term contracts should be considered.

5.2.2.9 WASTE DISPOSAL CREDITS OR DEBITS

If a system can handle industrial waste, sewage, or sewage sludge, this system should receive financial credits. On the other hand if it produces sewage or other waste this disposal cost should be a debit.

5.2.2.10 PHYSICAL CHARACTERISTICS

Local land availability, hydrology, topography, drainage, geology, weather, wind direction, pest and odor control considerations, special characteristics of local utilities, traffic patterns, highway networks, zones, financing, all may be important considerations.

5.2.3 QUALITATIVE CHARACTERISTICS

Certain aspects, such as good resource recovery, environmental considerations beyond those required by law and political and social contingencies, may be important to communities. These are often not adequately reflected economically directly or indirectly. For reasons which are not economical, certain forms of energy or certain materials recovered might be favored. A system which has a large safety margin concerning unknown future environmental impact could be favored. Certain polluting factors might be considered more important than others. Air, water, noise, an attractive appearance, or smell might be particularly important.

Attitudes of existing managers of solid waste in the area and the image systems offer to observers could affect the choice of a waste disposal system.

5.2.4 OUTLINE OF CONSIDERATIONS

The following outline organizes the considerations mentioned in the previous discussion according to the data blocks in Figure 5-1. This outline furnishes a list of selection-criteria subjects.

REFUSE DATA

Type
Amount
Composition
Seasonal variability
Special wastes
Waste generation locations
Projected rate of generation

SOCIAL, LEGAL, ENVIRONMENTAL AND POLITICAL DATA

OSHA Standards

Political institutions
- who makes decisions
- regional authority

Public acceptance
- credibility
- existence of definite and apparent need (crisis?)
- aesthetic considerations
- image
- pest control
- odor
- past history
- community culture
- tax needs

Environmental concerns
- resources recovered
- energy recovered
- EPA Standards
- local pollution standards

MARKETS AND ECONOMICS

Capital investment
- equipment
- land cost
- amount of land
- working capital
- building
- planning
- economic life

Operating costs
- maintenance
- overhead
- direct labor
- materials
- utilities
- taxes
- insurance
- interest
- disposal of residue
- fringe benefits
- fuel costs
- administration
- transportation

Plant siting
- relation to markets
- relation to solid waste source
- physical constraints
- relation to social attitudes

Markets of recovered energy
- availability
- form of recovered energy
- reliability of supply and demand
- new market possibilities
- transportation
- market price fluctuations
- contract possibilities

Markets of by-products
- availability
- form of products
- reliability required
- research and development current and needed
- transportation
- price fluctuations
- contract possibilities

Sensitivity to price of products
- scrap markets
- local conditions
- contracts

PHYSICAL AND TECHNICAL DATA

Residue disposal
- land
- transportation

Installation time
- study time
- construction
- start up
- time limits on existing method of disposal

Adaptability
- capacity needs
- future MMR composition changes
- future legal changes
- market changes
- political and social changes
- technical developments
- location desirability changes
- mode of operation

Capacity expansion
- modular units
- ease of expansion

Labor requirements
- skill requirements
- vulnerability of system to misuse

Plant siting
- land availability
- hydrology
- topography
- drainage
- geology
- weather
- wind direction
- pest control
- traffic

Conversion technology
- status of development
- data available
- overall technical reliability
- operating experience

Maintainability and repairability
- costs
- equipment
- building
- grounds
- preventive maintenance program
- personnel requirements

Redundancy and storage
- reliability of disposal
- reliability of production
- reliability demanded by markets
- reliability demanded by social attitudes
- reliability demanded by managers

5.2.5 Discussion of Tradeoffs

There are relationships between the different criteria mentioned which suggest that to increase a system's desirability in one area might be to decrease it in another. Another common and obvious example is the relationship between capital cost and maintenance costs. Often, if one is higher the other is lower for similar systems. Built-in redundancy, flexibility, and short installation time are desirable features which would generally increase capital cost and might even increase operating costs. In addition, built-in redundancy might increase installation time. There are, indeed, many of these interrelationships.

If all of the characteristics mentioned were to be considered with their relationship to each other, the result would be an overwhelming and confusing collection of ideas. The next two sections contain a suggested way to simplify the decision process and gain useful information.

5.3 Selection of Feasible Options

5.3.1 Preliminary Selection Criteria

When a particular community needs a new waste disposal system it should consider all the options available. Many of these options are, however, not feasible for one reason or another in particular locations. Hence, to analyze in detail all the systems available would be unnecessary and also costly.

To determine the feasible options, a community can first of all consider the previously given check list and determine which factors are to be used as preliminary selection criteria subjects. The community must then put the germane numbers or qualifications on these factors. As an example, the following is a list of criteria which a hypothetical community might use in screening all the technical options available. In order for the process to be eligible for further consideration it must fulfill each requirement below such as:

1. Because of a long term contract already held with the city, it must handle the oily waste from Acey Industry.

2. System must handle 1000 metric tons of MMR/day at the time of installation and be expandable to 2000 metric tons/day by 1985.

3. System must meet all EPA standards thru 1985 as to air, land, and water pollution.

4. Major breakdowns should occur no more than twice a year. When the plant shuts down, operation should be restored within 24 hours.

5. The net operating cost per ton of MMR must not exceed $8.50 assuming public financing at 8 percent interest.

6. System should recover at time of installation 90 percent of the tin cans a and 50 percent of the aluminum - the only markets available at this time.

7. Total landfill requirements must not exceed 20,000 square meters per year at depths determined by a geological survey in each potential area.

8. To reduce collection costs, system should be installed in two modules in different geographical locations.

9. Sites should be within 18 kilometers of the city center and be agreed upon by citizen referendum within a radius of 4 kilometers of the site.

10. System should have had running experience for 2 years at a capacity of at least 500 metric tons per day.

This list is only an illustration. The reasons for the various concerns and numbers relate to the individual community. Even after the various options have been checked for these criteria it may turn out that one or more of the criteria can be changed allowing more options to be feasible and eligible for further investigation.

Preliminary selection criteria themselves might vary in number from just a bare minimum of two or three important factors, to an exhaustive list covering all aspects of the problem. The number of criteria chosen results from a tradeoff analysis between:

1. too few considerations making selection meaningless and,

2. too many considerations making selection impossible and costly.

5.3.2 Technical Options Available

Another input to the selection of feasible options is the number and kind of technical options available. Before a community can adequately use any plan, it should be technically viable. Unless a community can get substantial financial assistance to embark on an experimental project, it is preferable to screen out those options which are in the development stage.

Among possible options, those which produce energy fall basically into the following categories:

1. incineration
2. pyrolysis
3. biodegradation.

Each of these types have their attendant advantages and disadvantages which are discussed in Chapter 3. It should be noted that water wall incineration is the only energy recovery method currently well developed.

5.3.3 Screening

Once the selection criteria have been developed and a lit of available options made, the next step is to see whether or not each option can achieve all the criteria. In the preliminary selection criteria example given, an option that meets all 10 criteria is eligible for further detailed analysis.

Recognizing the difficulty in obtaining options that meet all these criteria a community may wish to divide the criteria into two categories. These would be:

1. Criteria that must be absolutely met - no negotiation possible. Again referring to the example cited previously, items No. 1, 2, 3, and 9 might fall into this category.

2. Criteria that may not have to be absolutely met - some negotiation possible. The balance of the items in the example, i.e., No. 4, 5, 6, 7, 8, and 10 might fall into this category.

This preliminary selection process may be done several times with alternate sets of criteria. This selection process is meant to be very flexible incorporating new information and insights where possible.

The output from this process is then a list of feasible processes available for further analysis to determine which is the optimum solution for the community. This screening process is shown on the left side of Figure 5-2 located in the next section.

5.4 ANALYSIS OF FEASIBLE SYSTEMS

5.4.1 Introduction

The analysis of feasible systems is concerned with the final selection of a waste-disposal system. This analysis takes place after the initial screening process has narrowed the choice of systems to those which will meet the major requirements of a community.

The analysis of feasible options considers both qualitative and quantitative factors. Analysis of the qualitative factors involves the assignment of weights to various factors such as the adaptability of the system, its public acceptance, and its installation time. The ability of a system to achieve a certain factor and the factor's weight are used to provide a score - an indication of system desireability. All quantifiable costs associated with the project are subjected to a traditional economic analysis. These two numerical inputs are then used by a decision maker as a guide in selecting the final process. The overall procecedure is shown in Figure 5-2. It is a more detailed version of Figure 5-1. This section deals, however, only with the material after the feasible options have been determined. First of all, a suggested economic analysis is given, Then, the determination of

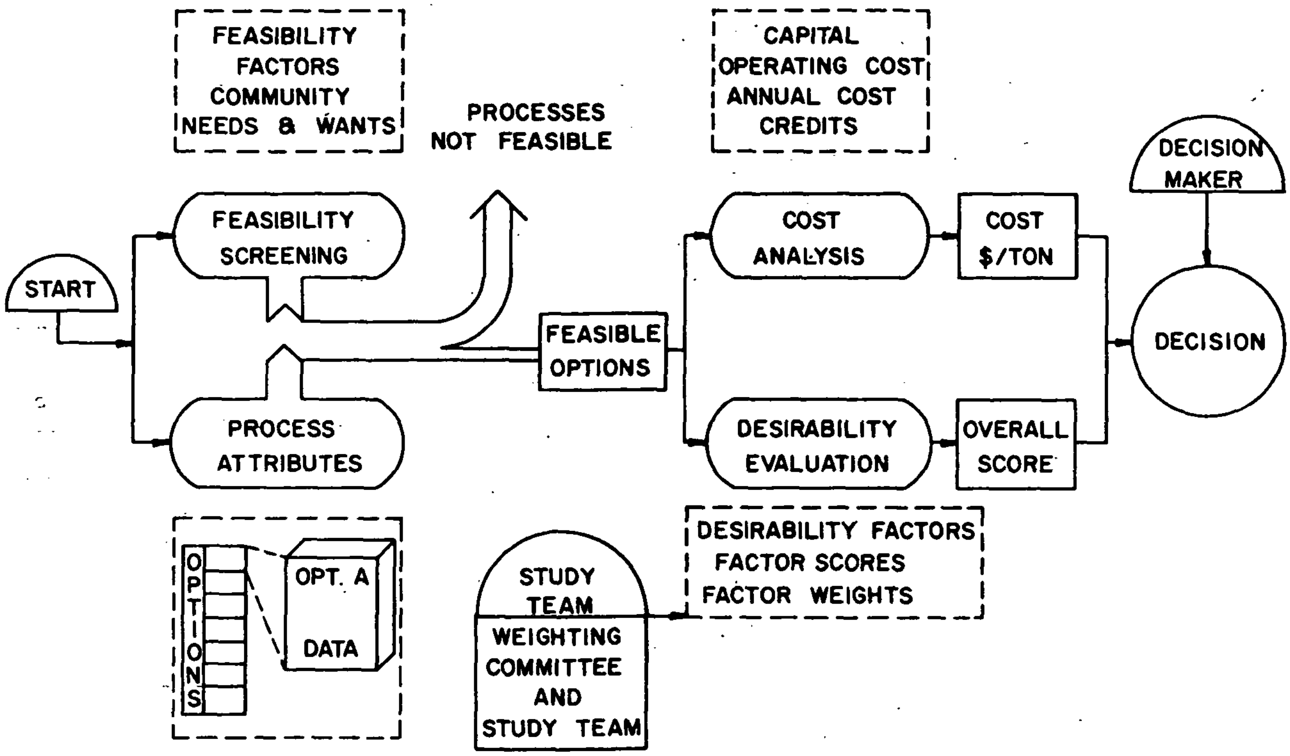

FIGURE 5-2
DECISION PROCEDURE

desirability is given.

5.4.2 Evaluation Techniques

5.4.2.1 ECONOMIC ANALYSIS

Sound estimates of both the initial capital expenditures and the yearly operating costs and revenues provide the foundation for a valid economic analysis. The forms shown in Figure 5-3 and Figure 5-4 are provided as a means of summarizing these estimates. The forms shown in Figure 5-5 and Figure 5-6 provide the format for the economic analysis.

The net annual cost for a given system can be determined by adding the annual capital cost to the annual operating cost and subtracting the annual credits or revenues. This dollar amount is divided by the metric tons per year handled to obtain a dollar per metric ton cost. The data for this calculation are listed in Figure 5-3 and Figure 5-4. To obtain the annual capital cost the interest rate and economic life period must be established. An engineering economy book such as reference 5-8, may be consulted for the appropriate capital recovery factor.

For the economic analysis, data estimated for each year of operation are transferred to the Cost Analysis Sheet (Figure 5-6) from the Process Cost Sheet (Figure 5-3).

The Cost Analysis Sheet is designed to accommodate either private or municipal ownership of a community's disposal system. A private owner will pay income taxes and also completes Columns 2, 5, and 6, on the form. It will be financially advantageous for the private owner to use an accelerated form of depreciation and claim the maximum amount of depreciation possible in the early years of his investment.

The economic analysis is a standard technique called the Present Worth Analysis found in engineering economy books. The sum of all the present worth amounts in Column 9 yields the total present worth of the cash flows associated with the disposal system under consideration. The system having the largest positive value as its present worth is the most financially desirable system.

Another standard economic analysis is the Equivalent Annual Cost Analysis. Provision for carrying out this analysis has been made on the bottom of the Cost Analysis Sheet.

5.4.2.2 DESIRABILITY ANALYSIS

Introduction. To be thorough in analysis, the feasible processes must each be evaluated in terms of not only economic but also social, environmental and political factors that are pertinent to the

CAPITAL COSTS (TOT. $)	DOLLARS/YR.	COMMENT
Land		
Preprocessing Eqmt		
Processing Eqmt		
Postprocessing Eqmt		
Utilities		
Building & Roads		
Site Preparation		
Engr. & R & D		
Plant Startup		
Working Capital		
Misc.:		
TOTAL		
OPERATING COSTS ($ PER YR)		
Maint. Material		
Maint. Labor		
Dir. Labor		
Dir. Materials		
Overhead		
Utilities		
Taxes		
Insurance		
Interest		
Disposal of Residue		
Payroll Benefits		
Fuel		
Misc.:		
TOTAL		
CREDITS ASSUMED ($ PER YR)		

FIGURE 5-3
PROCESS COST SHEET

	DOLLARS/YR.	COMMENT
Fuel:		
Liquid		
Gas		
Solid		
Power:		
Steam		
Electricity		
Hot Water		
Magnetic Metals		
Nonmagnetic Metals		
Glass		
Ash		
Paper		
Other:		
TOTAL ($ PER YR.)		

FIGURE 5-4
RESOURCE RECOVERY DATA

Capital Costs

	19__	19__	19__	19__	Total
Land					
Building					
Equipment					
Site Preparation					
Plant Start Up					
Working Capital					
Other:					
______________					
______________					
TOTAL					

Operating Costs

Year	Material	Labor	Fuel	Utilities	Residue Disposal	Other	Total
19__							
19__							
19__							
19__							
19__							
19__							
19__							
19__							
19__							
19__							
19__							
19__							
19__							
19__							
19__							
19__							
19__							
19__							
19__							
19__							
TOTAL							

FIGURE 5-5
CASH EXPENDITURE SUMMARY

community. It should be noted that while similar factors may have been used earlier for feasibility screening, they are used more qualitatively in the desirability analysis.

Every feasible process will not satisfy completely all of the economic, social, environmental and political desires of a community. For the purpose of deciding which feasible process is to be selected, each should be evaluated as to how desirable it is with respect to the set of factors considered. These factors are called desirability factors. To each of the factors for each process, a measure of the desirability may be given. Since all factors are not likely to be equally important to the community, there is a need of assigning weights to these factors. These weights are then used together with desirability measures to arrive at an overall weighted measure of process desirability.

The evaluation technique is presented in the following sections. After describing some basic ideas that are used in structuring the technique, a step by step procedure is given.

The evaluation procedure is not designed to produce a final decision. Instead, it is a procedure by which due consideration of many relevant factors is systematically taken into account for all the selected feasible systems. Furthermore, it is a method to reduce the bulk of information down to a few summarized measures which are comparable between different processes. Since these measures

Year	1 Total Amt. Subject to Dep.	2 Dep.Amt.	3 Tot. Op. Cost	4 Revenue	5 Taxable Income	6 Income Tax	7 Net Cash Flow	8 Present Worth Factor	9 Present Worth
19__									
19__									
19__									
19__									
19__									
19__									
19__									
19__									
19__									
19__									
19__									
19__									
19__									
19__									
19__									
19__									
19__									
19__									
19__									
19__									
TOTAL									

CAPITAL RECOVERY FACTOR

EQUIVALENT ANNUAL COST

FIGURE 5-6
COST ANALYSIS SHEET

describe the overall characteristics of each process to the community, they will serve along with the economic analysis as a useful aid for the decision maker(s) in making a final selection.

To determine the factors in the desirability evaluation, a committee should be formed of members representing various views and interests in the community's solid waste management program. Before evaluation, relative weights are assigned to each of the desirability factors. In order to assign weights that reflect the composite true opinion of the community, the factors should be well understood by each committee member and weighted without regard to any particular process.

Although many desirability factors are interrelated, they will be evaluated as independent factors one at a time. In order to arrive at an overall measure of the desirability, it is necessary to evaluate each factor based on some common unit. A (0 to 1) measure is used to rate all the factors such that a highly desirable factor is given a score very close to 1 and a highly undesirable factor is given a score close to 0. This is also done for certain quantifiable factors which qualitatively fit into the desirability analysis, e.g., high capital cost may be undesirable.

Decision analysis techniques for solving problems involving qualitative factors have been mostly confined to an analysis at one point in time. However, a process, once selected, is expected to operate satisfactorily for many years; therefore the desirability score for a particular process should be obtained for the expected operational life. An attempt is made to allow for multi-period evaluation in the proposed procedure.

<u>Process Outline</u>. The mathematical model used for the proposed desirability evaluation procedure is a simple linear, non-interactive model with equally spaced time intervals. An overall weighted score (υ) for the desirability of a process is given by,

$$\upsilon = (1/(T)(I))\sum_{j}\sum_{t} W_j(t) \sum_{i} x_{i,j}(t)$$

where $i = 1, 2, \ldots, I$ - the number of Study Team Analysts,

$j = 1, 2, \ldots, J$ - the number of desirability factors (see Table 5-1)

$t = 1, 2, \ldots, T$ - the number of periods under study,

$x_{i,j}(t)$ is the desirability score of the j^{th} factor for period t evaluated by analyst i (see Figure 5-7), and

$W_j(t)$ is the previously mentioned committee's weight assigned to the j^{th} factor for period t and is obtained by averaging the committee members' assigned weights, $w_{j,k}(t)$, k=1,2, . . . K, where K is the number of members on the Weighting Committee.

When a relatively small number of factors, say less than 5, is to be evaluated, their weights can be easily assigned by simple methods such as ranking. The so called DARE method proposed by Klee (ref. 5-9) appears to be a simple and yet powerful technique for assigning weights to a large number of factors. It is a modified version of the Pair Comparison method. By assigning a weight ratio to a factor compared only with the next one in the list, the number of comparisons is drastically reduced. This is certainly an advantage.

The method of assigning weights ($w_{j,k}(t)$) is described below with an example. It is to be done by each Weight Committee member - "K" in number.

1. Given a set of desirability factors f_j, j=1,2,. . . J, list the factors (J=5 in the example) in any arbitrary order as shown in the first column of Table 5-1.

TABLE 5-1
WEIGHT DETERMINATION EXAMPLE
FOR ONE PERIOD

Factor f_j	Ratio $R_{j,k}$	Raw Weight $Q_{j,k}$	Weight $w_{j,k}(t)$
f_1	2.0	0.66	0.10
f_2	0.1	0.33	0.05
f_3	2.5	3.25	0.50
f_4	1.3	1.30	0.20
f_5	1.0	1.00	0.15
		6.54	1.00

2. Starting from the top of the list, assign a ratio, $R_{1,k}$ representing the k^{th} committee member's judgment of the importance of the first factor compared to the second factor in the list.

3. Continue assigning ratios to all the other factors one at a time in the order they are listed, except the last one which is assigned a ratio of 1 ($R_{5,k}$). The ratio assigned to a factor is an importance ratio between this factor and the one immediately below it in the list. In the example, f_1 is judged twice as important as f_2, f_2 is one-tenth as important as f_3, f_3 is two and one-half times as important as f_4, and f_4 is one and three-tenths as important as f_5/

4. After assigning ratios, they are entered in the second column and their corresponding raw weights can be computed by first letting the last factor be the base weight of 1, and using the formula

$$Q_{j,k} = R_{j,k}Q_{j+1,k}$$

beginning with j = J-1 and ending with J=1. These are shown in the third column. (Note that $Q_{5,k}$ is defined as 1.)

Examples of the Q's computed are shown below:

$Q_4 = R_4\ Q_5 = (1.3)(1.0) = 1.30$

and $Q_2 = R_2\ Q_3 = (0.1)(3.25) = 0.33$

5. Compute the weights, $w_{j,k}(t)$, by dividing the raw weights by the sum of all the raw weights. The last column now contains the weights which will be used to arrive at the average weights ($W_j(t)$) - a weight for each factor for each period of study.

Once the weights of the desirability factors are determined, the desirability score $x_{i,j}(t)$ of each process with respect to each factor and period must be determined by the "I" Study Team Analysts. The scoring method proposed here requires independent evaluation of each process with respect to each desirability factor.

Actual evaluation using the proposed method is done by scoring a value between 0 and 1, according to the analyst's judgment on how well the process satisfies the community desirability factors one at a time. To facilitate the evaluation procedure, it is helpful to specify for each factor the characteristics which are the most desirable and the least desirable to the community concerned (see Table 5-2).

When evaluations are made for multiple periods, a convenient way for the analyst to use a form such as the one shown in Figure 5-7.

The crosses in the form illustrate a sample raw score done by one analyst for the present time and for a 20 year study considering 1 year periods. In the model presented, these scores are weighted by multiplying each by a corresponding set of yearly weights - ($W_j(t)$). For a preliminary analysis without weights, a score

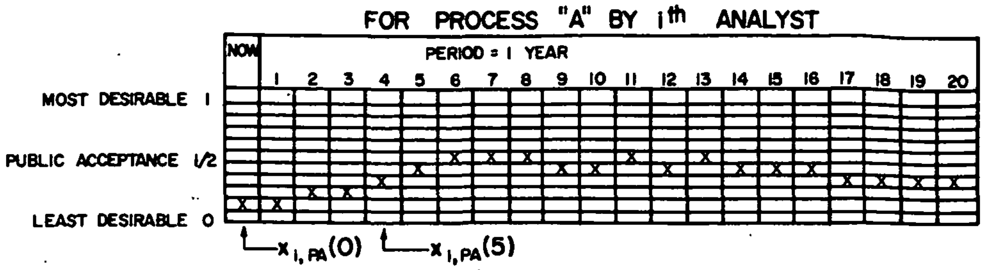

FIGURE 5-7
DESIRABILITY SCORE EXAMPLE

could be obtained by dividing 21 (T), the number of scores, into the sum of the 21 raw scores. For the above illustrative example, the unweighted score is 9.5/21 = .45 for the public acceptance of the process being evaluated. Such a score could mean that, in the opinion of the analyst, the process should be changed in order to increase the community acceptance.

When each of the feasible processes is evaluated with respect to all the factors by each analyst in the team, the input data generation is complete. Computations of the weighted scores (υ) for each process can be performed using the mathematical model presented earlier.

Process Elaboration. The following material is an elaboration of the process previously presented. A list of possible desirability factors is given. Also a step by step process is outlined. A form designed for use by the Weighting Committee and a form designed for use by the Study Team Analysts in their desirability scoring of the feasible processes are presented.

While each community should have its Decision Committee determine the important desirability factors for weighting and evaluation, a recommended list of factors has been selected as shown in Table 5-2. These are based on the outline of important factors presented in Section 5.2.4. Note that the most and least desirable levels of each factor are also specified in the table. It is believed that a slight addition to or subtraction from the list will be adequate enough for most locales. Also noted is the fact that the exact meaning of each factor might vary with the community.

The step by step process is as follows:

1. The Weighting Committee meets to:

   a. list desirability factors, with reference to those shown in Table 5-1, to be used for evaluating feasible processes. The Committee Members should have general agreement as to the meaning and interpretation of each of the factors chosen,

   b. decide the total number of years for which evaluations are to be made. This is a difficult task since it involves projecting events into the uncertain future. However, it is considered very important as it tends to force each member to look beyond the present.

   c. decide the number of periods, or the time intervals within the study life. For example, a study life of 20 years with 5 equal time intervals in addition to the present means a total of 6 evaluations, one for the present and one for each four year interval.

2. Each Committee member should weigh each desirability factor according to his or her judgment as to its relative importance for each of the periods in the study life. A weighting sheet shown in Figure 5-8 is designed for assigning the paired weight ratios ($R_{j,k}$ - refer to Table 5-1). The method has been explained previously. Computation of average weights ($W_j(t)$) must then be done for each period.

3. Analysts of the Study Team should meet to familiarize themselves with the list of desirability factors selected by the Weighting Committee. Understanding of the factors is most important in order to achieve good performance in evaluation. Discussions are encouraged at this point to clarify what each factor represents.

4. Each Study Team Analyst indepen-

TABLE 5-2
DESIRABILITY FACTORS

	FACTOR	MOST DESIRABLE	LEAST DESIRABLE
1.	market of recovered energy	guaranteed by contract	new market needs to be created
2.	market of by-products	guaranteed by contract	new market needs to be created
3.	residue disposal	none	50% or more and/or special disposal
4.	environment	no pollutants	may not meet some standards
5.	health and safety	completely safe	potential hazards in plant, to public
6.	installation time	will meet schedule	likely to delay beyond required date
7.	capital investment	minimal and/or easily financed	almost impossible to finance
8.	operating cost	low	high
9.	management	simple or sub-contracted	difficult to manage plants and labor
10.	adaptability	adaptable to any new technology	cannot be modified
11.	public acceptance	attractive to public	strong resistance from public
12.	capacity expansion	fully expandable	no room for expansion
13.	input requirement	any composition of refuse/fuel	operation stops if input is inadequate
14.	labor requirement	few and unskilled	many and highly skilled
15.	plant siting	no restrictions	only one possible site
16.	conversion technology	well developed and commercialized	experimental
17.	maintainability and repairability	done without stopping production	prolonged shutdowns frequently
18.	resource and energy recovery	complete recovery of energy and resources	low thermal efficiency and nothing recovered
19.	back-up and storage	continuous operation assured	no back-up, no storage
20.	market price fluctuation	minimal affect	extremely sensitive

dently evaluates each factor for each period, one process at a time. Adequate time is allowed for obtaining relevant information about the process in order to evaluate the factors. If a process is very desirable with respect to a factor a score closer to 1 is given. A process very undesirable with respect to a factor is given a score close to 0. A scoring sheet is designed for this purpose (Figure 5-9). A cross is marked in the box corresponding to the analyst's score of desirability for the time period considered.

5. Compute weighted scores (υ) for all the processes evaluated. This can be done by an ad hoc group or a computer.

6. List the processes rank-ordered according to the overall weighted scores. This list together with the results of the economic analysis discussed in Section 5.4.2.1 are now submitted to the decision makers for their use in making a final selection.

Post-Evaluation Analysis. It is apparent that most municipal officials are particularly concerned with the net unit cost of refuse disposal. This information from the economic analysis can be used along with the desirability score to judge the merits of a particular process with respect to the other feasible processes. The decision maker may decide on the basis of the two pieces of information, cost and score, provided to him for each process. Since the cost estimates are subject to variation because of market uncertainties, it will be more informative to the decision makers if some kind of sensitivity analy-

Weighting Committee Member (k)____________________ Date__________

DESIRABILITY FACTORS	PAIRED WEIGHT RATIOS FOR EACH PERIOD $(R_{j,k})$																				
	Now	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. market of recovered energy																					
2. market of by-products																					
3. residue disposal																					
4. environment																					
5. health and safety																					
6. installation time																					
7. capital investment																					
8. operating cost																					
9. management																					
10. adaptability																					
11. public acceptance																					
12. capacity expansion																					
13. input requirement																					
14. labor requirement																					
15. plant siting																					
16. conversion technology																					
17. maintainability & repairability																					
18. resource and energy recovery																					
19. back-up and storage																					
20. market price fluctuation																					

FIGURE 5-8
WEIGHTING WORK SHEET

sis is presented. One simple method is given as an example below.

Figure 5-10 is an example presentation of results of the evaluation of six alternative waste disposal processes including systems for energy and resource recovery. Their weighted scores (υ) and net cost per metric ton of refuse disposal are listed in the second and third columns respectively. The last column shows the expected cost ranges due to market uncertainties. This information may also be plotted as shown in the graph. From the illustrations, it is readily seen that at least processes C and F should probably be eliminated from further consideration. Process C has a very large cost range, which may be an indication that the process is either still in its very early development stage, or the market for its products is highly uncertain, or both. Process F may be a much better developed process but it is expenxive.

There are available many other measures which attempt to combine the cost with desirability score to arrive at a single measure for each process. Examples are cost-benefit ratio studies or cost-effectiveness analyses. They are not discussed in this report.

5.5 FINAL DECISION

5.5.1 USE OF RECOMMENDATIONS FROM DECISION PROCEDURE

The results of the decision procedure will be a list of technical options which have been screened to make sure each meets minimum community criteria and then analyzed in more detail for economics and desirability. It is unlikely that any option will unanimously be accepted by all politicians or members of the general public. Neither will it be an optimum technical solution since the technology in this area continues to evolve.

The advantages and disadvantages resulting from the implementation of each option should be explicitly enumerated. Those making the final decision must evaluate this information and make judgments based on their own value preferences.

Consider, for example, a disposal solution which produces a very marketable product, has no residue to be landfilled, but which has a higher total cost per ton than an alternative disposal solution requiring a landfilled residue. Since the future outlook for landfill is uncertain due to possible legislation restricting or

Alternative Option______________________ Analyst__________________ Date__________

DESIRABILITY FACTORS	SCORES - BY PERIOD	NOW	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. Market of recovered energy	1 / 0																					
2. Market of by-products	1 / 0																					
3. Residue disposal	1 / 0																					
4. Environment	1 / 0																					
5. Health and safety	1 / 0																					
6. Installation time	1 / 0																					
7. Capital investment	1 / 0																					
8. Operating cost	1 / 0																					
9. Management	1 / 0																					
10. Adaptability	1 / 0																					

FIGURE 5-9
DESIRABILITY SCORE WORK SHEET

11. Public acceptance

12. Capacity expansion

13. Input requirement

14. Labor requirement

15. Plant siting

16. Conversion technology

17. Maintainability and repairability

18. Resource and energy recovery

19. Back-up and storage

20. Market price fluctuation

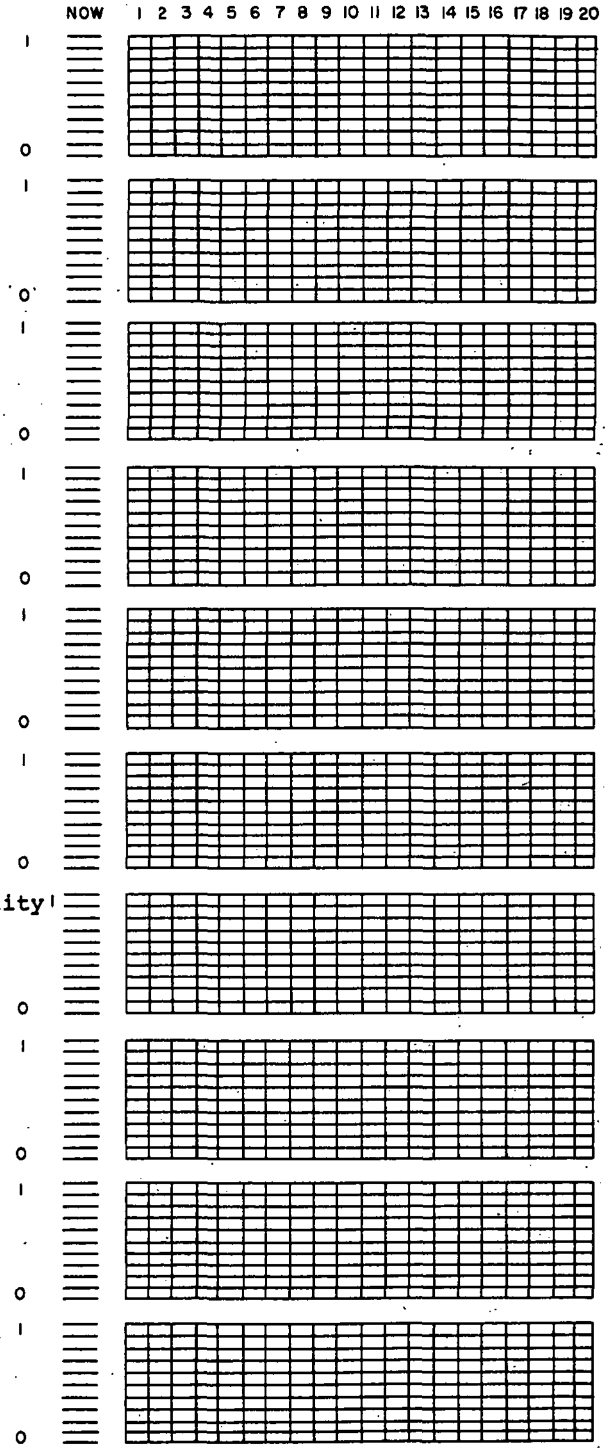

FIGURE 5-9 (CONTINUED)

OPTION	DESIRABILITY SCORE	$/ METRIC TON	COST RANGE
A	.62	5.25	4.00 6.00
B	.41	3.90	3.00 5.50
C	.79	8.40	6.00 10.50
D	.82	6.80	5.50 7.50
E	.73	6.10	5.00 6.50
F	.57	7.00	6.20 7.50

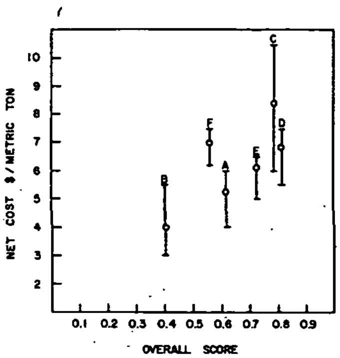

FIGURE 5-10
OVERALL SYSTEMS EVALUATION EXAMPLE

banning landfill all together, the decision may be to opt for the higher cost system.

The decision procedure is not intended to provide the decision maker with a definitive answer; rather it is a guide to ensure that all relevant variables are taken into account. The intent is to have the information as to cost and desirability available to the decision maker. But such information does not itself constitute a decision.

5.5.2 Responsibility for Final Decision

Who is responsible for the final decision about solid-waste disposal methods?

The material in Chapter 2 outlining the social aspects points out that, aside from well publicized pressure from ecologists, the main motivation for good waste disposal has been the public health of a community.

In discussing duties of municipalities a political scientist (Phillips, ref. 5-10), points out that:

> "Refuse disposal has such an obviously close relationship with public health that cities must make provision for it and must take steps to see that householders, industrialists, business enterprises and others comply with regulations or suffer penalties for noncompliance." (p. 594)

In the same reference it is noted that in 1951 the American Public Health Association suggested that community health programs should, among other things, include:

> " . . .direct supervision and regulation of many activities, such as protection of food, water, and milk supplies, control of nuisances, regulation of housing, inspection of hospitals and other health facilities, disposal of wastes, ... " (p.530) (underlining for emphasis).

It is concern for public health that places the responsibility for waste disposal squarely on local governmental units.

Since these governmental units, in turn, are responsible to the people, the people themselves are ultimately responsible for good waste disposal. In today's society, people must be supportive of waste disposal systems which not only maintain a healthful environment for themselves, but which also ensures a livable environment for future generations.

An example of direct citizen participation in solid waste decisions is the previously cited study of the Rochester, New York, solid waste problem done by volunteers from the Rochester Engineering Society (ref. 5-6). In a related example the county in which Rochester is located has a Solid Waste Management Advisory Council which includes persons representing the general public (ref. 5-11).

In summary, the responsibility for waste disposal falls on the governmental units responsible for overall public health. The ultimate responsibility however, lies with the general public who, in producing the waste, must not only allow it to be picked up but must also assure that it is properly put down.

5.5.3 Examples of Decision Structures

Many states have recently legislated regional structures for determining and implementing waste disposal methods. We will consider, briefly, plans in New York, Texas, and Connecticut. The political boundary and reference for each plan studied is given below:

Connecticut - entire state (ref. 5-12)

New York - one county (ref. 5-11)

Texas - three counties (ref. 5-13)

In Connecticut and Texas the Waste Disposal Authority was set up by the state legislature while in New York it was done by the county government.

The following are some pertinent details of each system considering primarily overall responsibility and final decision authority.

Connecticut. The Connecticut Resource Recovery Authority (CRRA) has been set up as a regional waste authority for the entire state. The CRRA is responsible for:

"1. The planning, design, construction, financing, management, ownership, operation and maintenance of the solid waste disposal, volume reduction and resources recovery and support facilities considered necessary, desirable or appropriate to carry out the state plan.

2. The provision of solid waste management services to municipalities, regions and persons; the recovery of resources from solid wastes; and the production of sufficient revenues from such services to permit CRRA to operate on a self-sustaining basis.

3. The utilization of private industry to contract for system development, management and operation, and for other services.

4. Assistance in the development of industries and commercial enterprises in Connecticut, based upon resource recovery, recycling and reuse.

5. Assistance with and coordination of local efforts directed toward source separation and recycling.

6. Planning, research and development, management and operation of the state's systems and facilities for solid waste management in order to permit continuing improvement for lowering operating and other costs." (ref. 5-12)

The authority is also empowered to appoint advisory councils perhaps with citizen representation. The authority must report quarterly to the Governor and annually to the General Assembly of Connecticut.

New York. Monroe County passed a solid waste disposal act affecting the entire county, including the City of Rochester. The purpose of the act is to:

> "enhance and improve the disposal and transporting of solid waste by establishing and enforcing standards, regulations, rules and procedure . ." (ref. 5-11).

This county-wide program authorizes the Department of Public Works to supervise disposal in the county while the county manager is empowered to enforce the provisions of the law.

In addition to the citizens and health officer previously mentioned, the Advisory Council has members from the county legislature, Department of Public Works and local businessmen dealing with refuse. One of its duties is to make recommendations to the Department of Public Works and the County Legislature for the improvement and implementation of solid waste management programs.

Conversations with officials of Monroe County revealed that because of the difficulty of finding a socially acceptable new landfill site, the County undertook the following steps:

1. an extensive market survey was made to determine what resource and energy materials could be sold in the local area,

2. recommendations were made to the Department of Public Works as to which materials could be feasibly recovered,

3. engineering firms were consulted as to the ease with which such systems could be implemented,

4. proposals from four firms were then evaluated by an interdisciplinary committee drawn from the Public Works Department, consulting engineers, the Rochester Engineering Society, environmental groups, the county legislature, a private Refuse Collectors Association, engineering schools, and local industries,

5. a disposal system recommendation was made to the county government,

6. bids were let by the county for construction and equipment.

Texas. The Gulf Coast Waste Authority, set up by the state legislature, is a three county waste disposal authority which includes Harris County (Houston). Its basic responsibility in areas of solid waste is quoted from Texas law.

> "The authority shall establish minimum standards of operation for all aspects of solid waste handling, including, but not limited to storage, collection, incineration, sanitary landfill, or composting." (ref. 5-13)

These standards are to be made public before implementation. The Texas Air Control Board and the Texas State Department of Health also must be consulted.

Master plans for waste disposal must be submitted to the Texas Water Quality Board for approval.

The act also provides for a council of mayors from the various cities affected. The mayors in turn elect the board of directors of the waste authority.

Thus, decisions concerning waste disposal are made (or at least monitored) by state and local governmental bodies charged with public health concerns.

Hopefully, these decisions reflect the needs and desires of the public represented by the various decision making bodies.

5.6 SUMMARY

Many communities have experienced considerable difficulty in using landfill, incineration, and composting for waste disposal purposes. Because of this, there is a trend toward using sophisticated waste disposal systems which maximize resource and energy recovery. The act of selecting a particular system for a community is complex. A proper choice cannot be made without a thorough investigation of many factors such as the political, legal, social and environmental implications of the choice. These implications must be considered simultaneously along with the more traditional economic and technical operating factors. A new dimension that also must be considered when energy production and resource recovery are undertaken is an analysis of markets.

Evaluation of all factors can be enhanced by following a formal procedure, such as that recommended in section 5.4. This procedure, which separately considers economic and desirability factors is designed to ensure that the relative advantages and disadvantages of all systems are systematically determined. The output of the procedure is one or more cost indicators and an index of system desirability. These, when put together, provide a tool for the decision maker to help judge the relative merits of the system candidates. (An example of the use of the procedure is given for Houston, Texas, in Appendix B.)

A note of caution should be given regarding the decision procedure. Even though the various factors are considered independent, in reality they are not. (A brief discussion of some of these interdependencies is given in section 5.2.) To include these relationships in a decision model is difficult indeed. The decision maker(s) must keep this in mind when using the procedure. Also, the overall perspective must be maintained. For example a particular process may not be screened out even though it does not meet some preliminary criteria but yet has other characteristics which will yield a high desirability score. It is assumed that the "human" aspect of the decision process will be concerned with factor relationships and an overall perspective not obvious in the procedure itself.

In the final analysis, the ultimate decision must be made by the governmental unit charged with the responsibility for waste disposal. The decision on how to handle this disposal must be made with an overriding concern for all aspects of public health and welfare. The decision procedure outlined in this chapter, used intelligently, should help ensure that such is the case in a local community.

REFERENCES

5- 1 Glysson, E. A., et al: The Problem of Solid Waste Disposal. College of Engineering, University of Michigan, Ann Arbor, Michigan, 1972.

5- 2 Gross, M. S.: A Unique Citizen Engineer Effort Associated with Solid Waste Disposal. ASME paper 73-DE-29, paper presented at Design Engineering Conference and Show, Philadelphia, pa., April, 1973.

5- 3 Midway Drops Limestone County Disposal Project. Houston Chronicle, July 30, 1974.

5- 4 City Asks Kent Help on Refuse Hauls. Grand Rapids (Mich.) Press, Jan. 18, 1973.

5- 5 Eastwood, D. G.: Opening Address at the City of Buffalo Resource Recovery Seminar. Buffalo, New York, June, 1974.

5- 6 Solid Waste Disposal Plans for Monroe County. Vol. I, II, and III. Rochester Engineering Society, Rochester, New York, April, 1972.

5- 7 Request for Proposal - Monroe County, New York. Resource Recovery Project, Rochester, New York, April, 1974.

5- 8 Grant, E. L., and Ireson, W. G.: Principles of Engineering Economy. Fifth ed., Ronald Press, 1970.

5- 9 Klee, A. J.: The Role of Decision Models in the Evaluation of Competing Environmental Health Alternatives. Management Science, Vol. 18, no. 2, Oct. 1971.

5-10 Phillips, J. C.: Municipal Government and Administration in America. Macmillan, 1960.

5-11 Solid Waste Management Law of the County of Monroe, State of New York, Motion No. 47 of 1973. Legislature of Monroe County, Aug., 1973.

5-12 A Proposed Plan of Solid Waste Management for Connecticut. General Electric and State of Connecticut Department of Environmental Protection, June, 1973.

5-13 Article 7621-d. Texas Civil Statutes as Amended, 1973.

APPENDIX A

RESULTS OF PRE-ENGINEERING DESIGN ON THE NAAS PROCESS

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RESULTS OF PRE-ENGINEERING DESIGN ON THE NAAS PROCESS

1. MATERIAL AND ENERGY BALANCES

A pre-engineering design has been completed on a NAAS process plant having a capacity of 1136 metric tons (1250 tons) per day. The material and energy balances were based on the following refuse composition (ref. A-1): Moisture 20 percent, organics 64 percent, inorganics 16 percent. Since the NAAS process uses a pyrolysis temperature in the range of 760° - 871°C (1400° to 1600°F), it will produce a product gas with a composition similar to that of the pyrolysis gas produced by the West Virginia pilot scale fluid-bed reactor (ref. A-2):

Gas	Mole %	Mole % with CO_2 free
CO_2	14.7	0
CO	27.1	31.7
H_2	41.7	48.9
CH_4	7.7	9.0
C_2H_6	0.1	0.1
C_2H_4	7.7	9.0
C_3H_8	0.4	0.54
C_3H_6	0.6	0.66

The refuse feed was assumed to have the following composition (ref. A-3):

(a) The ultimate analysis is given by:

Element	Wt %
C	55.84
H	6.92
O	37.01
N	0.04
S	0.17

which corresponds to the following typical structural formula

$$C_{30}H_{45}O_{15}N_{0.02}S_{0.03}$$

(b) Composition of Inorganics:

Component	Wt %
Glass	38.4
Rock and Dirt	28.9
Ferrous Metals	26.9
Aluminum	3.9
Non ferrous metals	1.9

The material balance was carried out on the following assumptions: (1) Maximum Operating Capacity is 1136 metric tons per day, (2) The efficiency of ferrous metal and aluminum recovery is 80 percent, (3) The heating value of the low grade coal used is 2.33 x 10^7 joules/kilogram (10,000 Btu/lb). (4) The coal has an ash content of 12 weight percent. The overall material balance is shown in Figure A-1 and an overall energy balance is shown in Figure A-2.

Input (metric tons/day)	
Moisture	227.0
Organics	708.0
Inorganics	201.0
Subtotal Municipal Solid Waste Feed	1136.0
Coal	58.0
Air	571.0
Total Feed to the NAAS Plant	1767.0
Output (metric tons/day)	
Pyrolysis gas	472.0
Water Gas	51.0
Subtotal Product Gas	523.0
Aluminum	6.2
Ferrous Metals	40.7
Slag	158.9
Subtotal Inorganic Output	205.8
NH_3	0.4
H_2S	1.4
Flue Gas	
CO_2	337.0
O_2	26.0
N_2	436.0
Subtotal Flue Gas	799.0
Moisture	236.4
Total Output From the Plant	1767.0

FIGURE A-1
NAAS MATERIAL BALANCE FOR A 1136 - METRIC TON PER DAY PLANT

Input (joules/day)

Heating Value of 1136 metric ton/day is 1.37×10^{13} (20% Moisture)

($13,000 \times 10^6$ Btu/day)

Heating value of 58 metric tons/day coal 1.35×10^{12}

($1,280 \times 10^6$ Btu/day)

Total energy Input 15.05×10^{12}

($14,280 \times 10^6$ Btu/day)

Output (joules/day)

Heating Value of 523 metric tons Product Gas 1.20×10^{13}

($11,370 \times 10^6$ Btu/day)

Heat Loss 3.05×10^{12}

($2,980 \times 10^6$ Btu/day)

Total energy Output 15.05×10^{12}

($14,280 \times 10^6$ Btu/day)

Approximate efficiency equals

$$\frac{1.200 \times 10^{13}}{1.505 \times 10^{13}} \times 100 = 80\%$$

FIGURE A-2
NAAS ENERGY BALANCE FOR A CAPACITY
1136 METRIC TON PER DAY PLANT

The process produces 472 metric ton (519 ton) per day of pyrolysis gas with a heating value of about 1.58×10^7 joules/Standard cubic meter (SCM) (530 Btu/SCF) when it is free from CO_2 and 51 metric ton of water-gas with a heating value of about 9.9×10^6 joules/SCM (330 Btu/SCF). The total volume of the mixed gas produced is 8.04×10^5 SCM/day (22.74×10^6 SCF/day). The product has an average heating value of 1.49×10^7 joules/SCM (500 Btu/SCF), an average molecular weight of 13.3, and an average composition of:

Gas	Mole %
CO	34.3
H_2	49.0
CH_4	7.7
C_2 fraction	7.9
C_3 fraction	1.1
	100.0

The overall energy balance of the plant was based upon the assumption that MMR has a heating value of 1.5×10^7 joules/dry kilogram (6500 Btu/dry lb.).

2. SIZING OF THE INDIVIDUAL EQUIPMENT

Kinetics data for pyrolysis of organic refuse are available (refs. A-4 and A-5). However, the kinetic data for the water-gas reaction and the reaction between the lime and carbon dioxide in the literature are not accurate enough for detailed engineering design. In designing the major NAAS equipment (pyrolyzer, combustor and dryers), the limiting factor is the exit-gas velocity rather than the residence time, since in a rotary kiln, the residence time can be varied over a very wide range by adjusting the inclination and the rotating speed of the kiln. But if the exit-gas velocity from a rotary kiln is too high, the entrainment of dolomite will be excessive, which will in turn result in unfavorable economics due to dolomite replacement and excessive cleanup needed. In this design, the maximum gas velocities from all major equipment are kept below 1.0 meter/sec (about 3 feet per sec).

The dimensions, power required, and construction materials for all individual equipment of the NAAS process plant are listed in Table A-1. Their purchase prices are listed in Table A-2. The major operating variables of the process are listed in Table A-3.

3. ECONOMIC ANALYSIS OF THE NAAS PROCESS

The analysis is based on the following assumptions:

a. The equipment costs are based on 1974 prices with a Marshall-Steven equipment Cost Index of 360.

b. The capital is borrowed at an interest rate of 10 percent a year, and the equipment has an average life of 20 years.

c. Carbon dioxide with a purity of 98 percent is worth \$8.80/metric ton.

d. The price of the product gas is \$0.71/10^9 joules (\$0.75/10^6 Btu).

e. Recovered metallic aluminum is worth \$330/metric ton.

f. The credits for ferrous metals, glass, and slag is assumed equal to the costs of handling them.

As shown in Table A-4, the total investment is \$12,467,500. Other pertinent capital costs are listed in Table A-4. The annual utility costs estimated are in Table A-5 and the annual operating costs estimated are in Table A-6. The economics of five operation cases are tabulated in Table A-7.

TABLE A-1
LIST OF EQUIPMENT FOR THE NAAS PROCESS

Name	Quantity	Capacity	Dia. (m)	Lgth. (m)	Construction Material	Power Req'd (KW)	Remarks
Shredder	2	46 metric ton/hr			Carbon steel	500	For rough shredding only
Magnetic Separator	1	46 metric ton/hr			Carbon steel frame	6	
Dryers	2		5.5	9.2		12	
Pyrolyzer	1		5.5	18.3	Partly austenitic steel lined	20	
Combustor	1		5.5	15		15	
Belt Conveyors	2-3	46 metric ton/hr				5-6	
Screw Conveyors	3	92 metric ton/hr			Stellite-25 screw Austenitic casing	12	Maximum temp 970°C
Screw Conveyors	1	92 metric ton/hr			Austenitic steel screw, Ferrite steel casing		Maximum temp 760° C
Screw Conveyors	4	46 metric ton/hr			Ferrite steel screw, Mild steel casing	6	Maximum service temp 371° C
Bucket Conveyor	1	92 metric ton/hr			Carbon steel casing, 310 SS chains and buckets	12	
Slag & Acid Remover	1	46 metric ton/hr Total solids			Stellite-25 screw Austenitic steel casing	6	Max service temp 970° C. Needs to be developed
Aluminum Separator	1	100 metric ton/hr Total solids			Austenitic steel moving parts, Ferrite steel casing	12	Needs to be developed, Max service temp 815° C
Steam Preheater	1	100 metric ton/hr Total solids			Austenitic Steel moving parts, Ferrite steel casing	12	Needs to be developed
Air Blower	1	3.58 x 10^4 m^3/hr			Carbon steel	530	Max Press 6.96 x 10^4 N/m^2
Gas Blower		3.2 x 10 m^3/hr			304 Stainless steel	580	Max Press 6.96 x 10^4 N/m^2
Flue Gas Multi-cyclone	1	3.58 x 10^4 m^3/hr at 149° C			Carbon steel		Press. drop 1.38 x 10^4 N/m^2
Product Gas Multi-cyclone	1	3.20 x 10^4 m^3/hr at 371° C			Carbon steel		Press. drop 2.07 x 10^4 N/m^2
Waste heat Boiler		9.1 metric ton/hr			Carbon steel		Gives steam at 3.45 x 10^5 N/m^2
Cooling tower	1	9.46 m^3/hr					
Air Preheater		2.18 x 10^{10}J/hr			Carbon steel shell 310 SS tubes	16	161 m^2

TABLE A-1 (CONTINUED)

Name	Quantity	Capacity	Dia. (m)	Lgth. (m)	Construction Material	Power Req'd (KW)	Remarks
Pump	1	13.3 m^3/min			Carbon steel	20	
Pump	1	13.3 m^3/min			310 Stainless steel	20	
Venturi Scrubber	1	Water rate 7.6 m^3/min			304 Stainless steel		With pumps and motor
Ash Hopper	1		1	13	Carbon steel		
Slag Hopper	1		1	3	Carbon steel		
Dolomite Hopper	1		1.5	33	Carbon steel		
Feed Hopper	1		2	4	Carbon steel		
Shredded Feed Hopper	1		17	7	Carbon steel		

TABLE A-2
PURCHASED EQUIPMENT INVESTMENT FOR NAAS PROCESS
(Designed Capacity 1250 metric ton/day of MMR)

A. Feed preparation		
2 Shredders (for rough shredding only)		$ 120,000
Magnetic Separator		21,000
	Sub-Total	141,000
B. Solid Transfer		
Belt Conveyors		50,000
3 High temperature screw conveyors		60,000
2 Medium temperature screw conveyors		20,000
4 Low temperature screw conveyors		16,000
1 Bucket elevator		9,000
	Sub-Total	155,000
C. Gas Transfer		
Air Blower		140,000
Gas Blower		200,000
	Sub-Total	340,000
D. Drying, Pyrolyzing, and Combustion		
2 Dryers		400,000
1 Combustor		500,000
1 Pyrolyzer		700,000
	Sub-Total	1,600,000
E. Solid Separation		
Slag and ash remover		30,000
Aluminum separator		52,000
Steam preheater		15,000
	Sub-Total	97,000

TABLE A-2 (CONTINUED)

F. Heat Recovery		
Waste Heat boiler		$ 25,000
Air Preheater		24,000
Cooling Tower		39,000
	Sub-Total	88,000
G. Storage		340,000
H. Miscellaneous		
D. C. Rectifier		15,000
2 Multicyclones		40,000
Concrete Pad		27,000
Front-end loader		38,000
	Sub-Total	120,000
I. Gas Purifying System		250,000
Purchased equipment Grand Total		$3,131,000

TABLE A-3

MAJOR OPERATING VARIABLES OF THE NAAS PROCESS (1136 METRIC TON/DAY)

Circulating rate of dolomite	909-1100 metric ton/day
Inlet temperature of the pyrolyzer	850°-960° C
Outlet temperature of the pyrolyzer	740°-760° C
Inlet temperature of the combustor (solid phase)	340°-350° C
Outlet temperature of the combustor (solid phase)	950°-960° C
Steam flow in pyrolyzer	71 metric ton/day at 670°-680° C
Saturated Steam pressure in waste heat boiler	2.1×10^5 - 3.4×10^5 N/m^2 (30 - 50 psi)

TABLE A-4

PLANT FIXED COST

Direct Fixed Cost		
Purchased equipment		$ 3,131,000
Purchased equipment installation		1,565,500
Instrument and Control		500,000
Piping (installed)		800,000
Electrical (installed)		570,000
Building (including services)		990,000
Yard improvement		279,000
Service facilities (installed)		900,000
Land		130,000
	Sub-Total	$ 8,865,500
Indirect Fixed Costs		
Engineering and Supervision		1,000,000
Construction Expenses		1,240,000
Contractors' Fee		262,000
Contingency and Start-Up		1,000,000
	Sub-Total	3,502,000
Working Capital		100,000
Total Investment		$12,467,500

TABLE A-5
UTILITY REQUIREMENTS AND COSTS FOR THE NAAS PROCESS
(1136 METRIC TON/DAY)

UTILITY	QUANTITY	ANNUAL COST
Steam	Self-producing	None
Cooling Water	1.33 m^3/min.	$ 13,800
Electric Power	2000 KW	40,000
	Total Annual Utility Cost	$ 53,800

TABLE A-6
OPERATING COSTS FOR THE NAAS PROCESS
(1136 METRIC TON/DAY OF MMR)

ITEM	QUANTITY	DOLLARS/YEAR
A. Direct Production Costs		
1. Raw materials		
Low-grade coal	58 metric ton/day	$ 126,720
Dolomite makeup	2 metric ton/day	52,800
2. Operating labor	7 persons/shift	336,000
3. Direct supervision and clerical labor		67,200
4. Utilities		53,800
5. Maintenance and repair		260,000
6. Operating supplies		65,000
7. Laboratory charges		50,400
	Sub-Total	$ 1,011,920
B. Indirect Fixed Charges		
1. Capital Cost Amortization (10% interest, 20 yr. life)		1,440,000
2. Interest		10,000
3. Local Taxes		250,000
4. Insurance		91,000
	Sub-Total	$ 1,791,000
C. Plant Overhead		$ 398,000
	Total Annual Operating Cost	$ 3,200,920

TABLE A-7
ECONOMIC BALANCE OF THE NAAS PROCESS - 5 CASES
(1136 METRIC TON/DAY)

Case A: Operating at 100 percent capacity with no CO_2 sale

1.	Income		Dollars/year
	a. Product gas sale		$ 2,813,300
	b. Aluminum sale		693,000
		Total Income	$ 3,506,300
2.	Operating Costs		Dollars/year
	a. Fixed Costs		$ 2,966,900
	b. Variable Costs		243,320
		Total Costs	$ 3,210,220
3.	Gross Annual Profit or $0.99/dry metric ton		$ 296,080

Case B: Operating at 100% capacity with CO_2 sale

1.	Income		Dollars/year
	a. Product gas sale		$ 2,813,300
	b. Aluminum sale		693,000
	c. CO_2 sale		980,000
		Total Income	$ 4,486,300
2.	Operating Costs*		$ 3,229,620
3.	Annual Gross Profit or $4.19/dry metric ton		$ 1,256,680

Case C: Operating at 50% capacity with no CO_2 sale

1.	Income		Dollars/year
	a. Gas sale		$ 1,406,700
	b. Aluminum sale		346,500
		Total Income	$ 1,753,200
2.	Operating Costs		$ 3,088,510
3.	Annual Loss or $4.46/dry metric ton		$ 1,335,310

* A capital cost of $250,000 for the additional gas purification equipment is added to the fixed cost.

TABLE A-7 (CONTINUED)

Case D: Operating at 50% capacity with CO_2 sale

1. Income		Dollars/year
a. Gas sale		$ 1,406,700
b. Aluminum sale		346,500
c. CO_2 sale		490,000
	Total Income	$ 2,243,300
2. Operating Costs		$ 3,107,960
3. Annual Loss or $2.87/dry metric ton		$ 684,760

Case E: Operating at 75% capacity without CO_2 sale

1. Income		Dollars/year
a. Gas sale		$ 2,100,000
b. Aluminum sale		$ 520,000
	Total Income	$ 2,620,000
2. Operating Costs		$ 3,148,900
3. Annual Loss or $1.76/dry metric ton		$ 528,900

REFERENCES

A-1 Boegly, W. J., Jr.; Hayes, V. O.; Hise, E. C.; Compere, A. L.; and Griffith, W. L.: Mius Technology Evaluation--Solid Waste Collection and Disposal. ORNL-HUD-MIUS-9, Sept., 1973, p. A-1.

A-2 Albert, S. B.; Scheeline, H.; Louks, B.; Ferguson, F. A.; and Marynowski, C.: Pyrolysis of Solid Wastes, A Technical and Economic Assessment. Standford Research Institute, (SRI Project ECC - 1886), Sept., 1972.

A-3 Material Recovery System, Engineering Feasibility Study. National Center for Resource Recovery, Inc., Washington, D. C., Dec., 1972, pp. 3-27.

A-4 Bailie, R. C.: High Energy Gas From Refuse Using Fluidized Beds. Final report to EPA, (Grant Number 5R01 EC 00399-03 EUH), Aug. 1, 1972.

A-5 Aldrich, D. C.: Kinetics of Cellulose Pyrolysis. Ph.D. Thesis, MIT, Part I, 1974.

APPENDIX B
HOUSTON APPLICATION

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Introduction

The application of the ideas of this report to Houston, Texas, serves as an example of how the concepts of converting solid waste to energy might relate to a particular city. This application is based on assumptions rather than a thorough study of Houston.

Preliminary Selection Criteria

For purposes of this example, the preliminary screening process (see Figure 5-2) is eliminated. Those processes for further detailed analysis are those in Table B-2. In reality some of these are not feasible in the Houston area but are included because of the availability of technical and economic information (see Chapter 3).

Houston is a rapidly growing city in land area, population, and industry. Solid-waste disposal is, at the present time, handled by private enterprises. In the recent past, the city has experienced failure in a few experiments with solid-waste disposal (ref. B-1). A compost plant was closed due to a limited market and public protest. Pollution complaints plagued both of these experiments. Both were extremely costly. Law suits and embarrassment were involved. Also there has been difficulty in locating new landfill sites. Private enterprise, in disposing of the waste, relieved the city of the problem for the moment. It is also noted that the private firms and the City per se each collect about one half of the MMR - 3300 metric ton daily from Houston.

Browning and Ferris, with a subsidiary, Resource Recovery, landfills and does a limited amount of recycling. About three quarters of the city's solid-waste is landfilled and about one quarter is left at the Resource Recovery plant located near the ship channel and near the industries which surround the channel.

Certain areas of Houston elect to contract with the private sector for a higher level of pickup service than the City offers. They pay the private firms and receive a refund from the City. If there was a drastic fluctuation in the number of customers taking part in such an arrangement, then the Department of Solid-Waste Management of the City would experience either a strain in refuse collection capabilities or a strain in the budget (ref. B-1), depending on the direction of the fluctuation.

Thus, Houston seems to require a solid-waste disposal system which is highly dependable and flexible.

Houston is already a large industrial port, and has an economy which includes market potentials for all the products of systems which convert solid-waste to energy (ref. B-2). The choice, therefore, of an energy converting process does not need to depend heavily on what is produced. However, some products may be more easily marketed than others. Information as to the markets' ability to gain letters of intent, contracts and manufacturing alterations, and public attitudes furnish needed facts about market feasibility.

Presently, Houston is involved in the initial stages of using newly constructed miniature incinerators which have no energy producing capacity (ref. B-1). These Consumat mini incinerators are to be located throughout the city at four or five sites.

Assumptions for Application to Houston

Assumptions are made which concern the aspects of Houston's future relating to systems of converting solid-waste to energy in Houston. These assumptions are made to facilitate a proposed answer to the question, "What technical option should the City of Houston use to convert solid-waste to energy?" The proposed answer depends on the assumptions below and, thus, reasons for the assumptions are given. Three of the assumptions are made solely on the grounds that they facilitate a proposed answer. These relate to cooperation of officials, both private and public. This cooperation is assumed, without evidence.

Throughout these assumptions, an attitude of cooperation by all involved parties is assumed. Many of the assumptions could be checked by polls, attitudinal checks, attempts at obtaining contracts and letters of intent and negotiations with those potentially involved.

The list of assumptions follows:

The basis for each assumption is stated just after the assumption when appropriate.

List of Assumptions: (Late 1970's)

1. By the late 1970's, landfill will not be an acceptable means of disposing of solid-waste in Houston. (In the last five years there have been no new landfill sites due to political, social and environmental reasons.) (See Chapter 2)

2. Due to recent failures with composting and incinerators in Houston, there will be a resistance to any major innovation in solid-waste handling.

3. The City of Houston will be in a position to make use of aggregates, such as glasphalt for paving, from the late 1970's through the late 1990's. (See Chapter 4, Research and Development.)

4. The utility companies will be in a position to use gaseous or solid fuel from MMR. They will be willing to do so. This assumption is made without evidence.

5. Browning and Ferris and Resource Recovery, Inc. will be willing to coordinate their facility for shredding solid-waste and extracting ferrous metals with a program of recovering energy from solid-waste (ref. B-3). Again, this assumption is made without evidence.

6. The MMR composition in Houston will be very near the typical in the U. S. (ref. B-2).

7. No system which contaminates the air will be acceptable. Land and water contamination will need to be minimal. Today's pollution problem in Houston suggests this assumption. Also, EPA regulations are an obvious constraint.

8. By the early 1980's manufacturing companies could be in existence to use materials recovered from solid-waste, if such materials are made available. (See Chapter 4)

9. Houston will be able to own and finance an energy conversion system at 8 percent interest over a 20 year period.

10. Paper, ferrous metals, glass and aluminum will continue to be marketable in Houston scrap markets. Throughout the foreseeable future, Houston will continue to export scrap. There will be continued growth of industry near the ship channel. There will continue to be a large integrated steel operation in Houston, glass container producers near and in Houston, paperboard mill and manufacturers of building products all which can utilize materials recovered from solid-waste. Aluminum reclamation in Houston will continue. Copper mines in the Southwest United States, near enough to Houston to use its steel cans, will continue to do so for copper precipitation (ref. B-2).

11. It is likely that transportation costs for scrap will become lower. (See Chapter 2)

12. There is a good chance that front end separation technology will improve and become more economical. Also the technology of maintaining and operating an energy conversion system will probably improve and become more economical. This is based on analyses in Chapter 3.

13. Energy prices will probably increase more rapidly than operating costs during the period 1980 - 2000. (See Chapter 4)

14. The City of Houston will be willing to shift its present tendency to use mini-incinerators to a plan which includes energy and material recovery from solid-waste. This assumption is made without evidence.

Decision-Making Data

The following material is the result of doing the economic and desirability analysis as indicated in Figure 5-2. The details of this process are in Chapter 5. The major difference in the Houston application is that it was done for only one time period (the present) while the more general model in Chapter 5 is for any number of periods.

The following tables are the result of the analysis for the "now" time period.

Table B-1, represents the results of work by a 5 man (K=5) Weighting Committee. This is the procedure given in Table 5-1 and attendant exploration.

Once the weights were established, 2 Study Team Analysts scored, using Figure 5-9, the desirability of each process in light of the 7 (J=7) desirability factors. The scoring results $X(i,j)$ of analyst No. 1 are in Table B-2 and No. 2 in Table B-3. The weighted scores from each analyst are given in column 1 of each table and are averaged to achieve the score (υ) for each process given in Table B-4.

Table B-5 combines a cost analysis with the score information of Table B-4. Table B-5 also includes a figure which pictures the cost along with the cost ranges and the overall weighted scores. The cost ranges depend on ranges in the market values of products of the energy conversion systems as noted in the assumptions in cost analysis for Table B-5 and B-6. Table B-6 is also an analysis independent of the decision model. All of the weights, scores, and evaluating words used in the decision model of Chapter 5 are based on opinions and judgment.

The assumptions used in the cost analysis are listed in Table B-7. The energy recovery processes in application are listed in Table B-8.

Decision-Model Results

The application of the decision-model techniques of Chapter 5 to the City of Houston has yielded the following ranking:

(1) St. Louis supplemental fuel process

TABLE B-1
WEIGHTING OF THE DESIRABILITY VECTOR FOR HOUSTON 1974

August 12, 1974

Weighting Committee Members	RAO			HALTER			DALTON			KUESTER			Van POOLEN			AVERAGE
Desirability Factors	R	K	W	R	K	W	R	K	W	R	K	W	R	K	W	W_i
Market	1.5	3.0	.24	1.0	20	.22	1.5	1.28	.13	1.0	8	.21	1.5	3.38	.35	0.23
Capital Investment	1.0	2.0	.15	1.0	20	.22	.5	.85	.08	1.0	8	.21	1.5	2.25	.23	0.18
Operating Cost	1.0	2.0	.15	1.0	20	.22	.75	1.69	.17	1.0	8	.21	2.0	1.5	.16	0.18
Public Acceptance	2.0	2.0	.15	5.0	20	.22	1.5	2.25	.22	4.0	8	.21	3.0	.75	.08	0.18
Plant Siting	.5	1.0	.08	4.0	8	.09	1.0	1.5	.15	.5	2	.05	.5	.25	.03	0.08
Conversion Technology	2.0	2.0	.15	2.0	2	.02	1.5	1.5	.15	4.0	4	.10	.5	.5	.05	0.09
Maintainability	1.0	1.0	.08	1.0	1	.01	1.0	1.0	.10	1.0	1	.03	1.0	1.0	.10	0.06
		13			91			10.07			39			9.63		1.00

TABLE B-2
WEIGHTED SCORES

	PROCESS WEIGHTS	COMPOSTING	BLACK-CLAWSON	PFEFFER-DYNATECH	WEST VIRGINIA	GARRETT	MONSANTO	UNION CARBIDE	ECO FUEL	CPU-400	ST. LOUIS	VON ROLL	
*Raw Score MARKETS	0.23	0.1	1.0	1.0	0.9	0.7	0.4	0.9	0.8	1.0	0.8	0.3	$X_{1,1}$
Weighted Score		0.23	2.30	2.30	2.07	1.61	0.92	2.07	1.84	2.30	1.84	0.69	
CAPITAL INVESTMENT	0.18	0.5	0.2	0.4	0.5	0.5	0.5	0.9	0.4	0.8	0.8	0.4	$X_{1,2}$
		0.90	0.36	0.72	0.90	0.90	0.90	1.62	0.72	1.44	1.44	0.72	
OPERATING COST	0.18	0.4	0.4	0.3	0.4	0.9	0.4	0.5	0.3	0.9	0.7	0.7	$X_{1,3}$
		0.72	0.72	0.54	0.72	1.62	0.72	0.90	0.54	1.62	1.26	1.26	
PUBLIC ACCEPTANCE	0.18	0.5	0.6	0.5	0.5	0.6	0.4	0.8	0.8	1.0	0.8	0.8	$X_{1,4}$
		0.90	1.08	0.90	0.90	1.08	0.72	1.44	1.44	1.80	1.44	1.44	
PLANT SITING	0.08	0.3	0.6	0.4	0.5	0.6	0.5	0.6	0.7	0.8	0.9	0.6	$X_{1,5}$
		0.24	0.48	0.32	0.40	0.48	0.40	0.48	0.56	0.64	0.72	0.48	
CONVERSION TECHNOLOGY	0.09	1.0	0.8	0.1	0.1	0.6	0.9	0.8	0.8	0.1	0.9	1.0	$X_{1,6}$
		0.90	0.72	0.09	0.09	0.54	0.81	0.72	0.72	0.09	0.81	0.90	
MAINTAINABILITY & RELIABILITY	0.06	0.9	0.7	0.8	0.4	0.4	0.6	0.5	0.7	0.4	0.6	0.6	$X_{1,7}$
		0.54	0.42	0.48	0.24	0.24	0.36	0.30	0.42	0.24	0.36	0.36	
SUM OF WEIGHTED SCORES		0.443	0.608	0.535	0.532	0.647	0.483	0.753	0.624	0.813	0.787	0.585	

TABLE B-3
WEIGHTED SCORES

	PROCESS WEIGHTS	COMPOSTING	BLACK-CLAWSON	PFEFFER-DYNATECH	WEST VIRGINIA	GARRETT	MONSANTO	UNION CARBIDE	ECO FUEL	CPU-400	ST. LOUIS	VON ROLL	
MARKETS	0.23	0.2	0.8	0.5	0.6	0.4	0.6	0.7	0.7	0.5	0.9	0.6	$X_{2,1}$
		0.46	1.84	1.15	1.38	0.92	1.38	1.61	1.61	1.15	2.07	1.38	
CAPITAL INVESTMENT	0.18	0.8	0.2	0.7	0.7	0.7	0.6	0.9	0.3	0.8	1.0	0.5	$X_{2,2}$
		1.44	0.36	1.26	1.26	1.26	1.08	1.62	0.54	1.44	1.80	0.90	
OPERATING COST	0.18	0.8	0.2	0.7	0.7	0.7	0.6	0.9	0.3	0.8	1.0	0.5	$X_{2,3}$
		1.44	0.36	1.26	1.26	1.26	1.08	1.62	0.54	1.44	1.80	0.90	
PUBLIC ACCEPTANCE	0.18	0.3	0.6	0.6	0.6	0.6	0.6	0.2	0.6	0.6	0.6	0.6	$X_{2,4}$
		0.54	1.08	1.08	1.08	1.08	1.08	0.36	1.08	1.08	1.08	1.08	
PLANT SITING	0.08	0.4	0.8	0.5	0.6	0.6	0.6	0.6	0.8	0.9	0.7	0.9	$X_{2,5}$
		0.32	0.64	0.40	0.48	0.48	0.48	0.48	0.64	0.72	0.56	0.72	
CONVERSION TECHNOLOGY	0.09	0.9	0.5	0.3	0.4	0.4	0.6	0.5	0.7	0.4	0.7	0.9	$X_{2,6}$
		0.81	0.45	0.27	0.36	0.36	0.54	0.45	0.63	0.36	0.63	0.81	
MAINTAINABILITY AND RELIABILITY	0.06	0.9	0.7	0.8	0.4	0.4	0.6	0.5	0.7	0.4	0.6	0.6	$X_{2,7}$
		0.54	0.42	0.48	0.24	0.24	0.36	0.30	0.42	0.24	0.36	0.36	
SUM OF WEIGHTED SCORES		0.555	0.515	0.590	0.606	0.560	0.600	0.644	0.546	0.643	0.830	0.618	

TABLE B-4

Process	Average Overall Weighted Score for each Process	Desirability Rank
1. Composting	0.499	11
2. Black Clawson	0.562	9
3. Pfeffer Dynatech	0.563	8
4. West Virginia	0.569	6
5. Garrett	0.604	4
6. Monsanto	0.542	10
7. Union Carbide	0.699	3
8. CPU-400	0.728	2
9. St. Louis Sup Fuel	0.808	1
10. Von Roll	0.600	5
11. Eco Fuel II	0.585	7

TABLE B-5
COST - SCORE ANALYSIS FOR A 1000 TPD IN HOUSTON

COST - SCORE ANALYSIS FOR A 1000 TPD IN HOUSTON

NO.	PROCESS NAME	OVER ALL SCORE	NET COST $ / TON	NET COST RANGE $ / TON
1	COMPOSTING	.50	4.60	3.85 - 6.43
2	BLACK - CLAWSON	.56	7.70	6.97 - 12.70
3	PFEFFER DYNATECH	.56	8.97	6.72 - 10.48
4	W. VIRGINIA UNIV.	.57	9.70	8.68 - 9.82
5	GARRETT	.60	4.90	2.37 - 7.13
6	MONSANTO	.54	7.30	4.42 - 8.82
7	UNION CARBIDE	.70	5.50	3.71 - 5.75
8	CPU - 400	.73	4.18	2.92 - 6.49
9	ST. LOUIS	.81	3.80	3.12 - 5.75
10	VON ROLL	.60	9.70	6.90 - 10.26
11	ECO FUEL II	.59		4.00 - 10.00

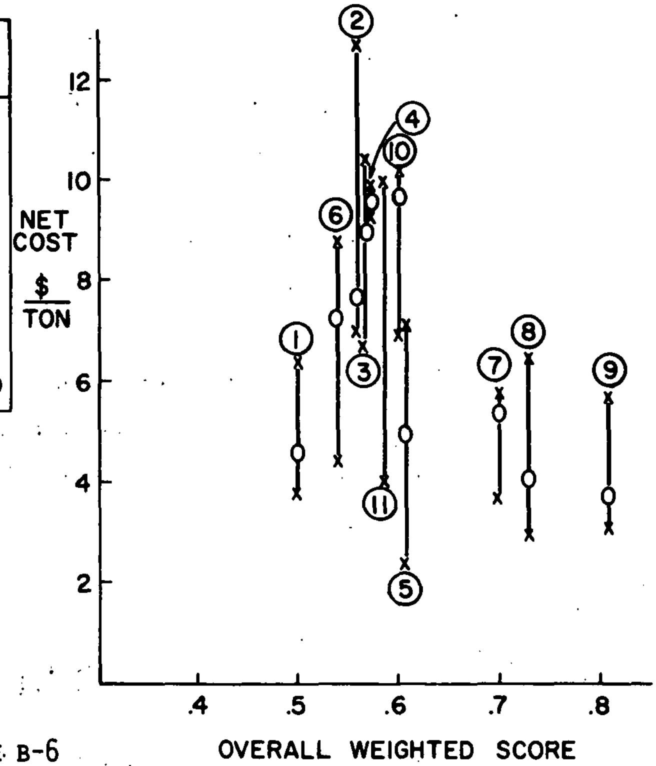

TABLE B-6

FACTORS	(1) FAIRFIELD-HARDY COMPOSTING	(2) BLACK-CLAWSON WET PULPING	(3) PFEFFER-DYNATHECH ANAEROBIC	(4) W. Va. U. FLUIDIZED BED	(5) GARRETT PYROLYSIS
(a) CAPITAL INVESTMENT	$20,120,000	17,430,000	18,333,000	12,870,000	12,951,000
(b) OPERATING COST, ANNUAL	1.245,000	3,150,000	4,908,000	3,010,000	3,075,000
(c) GROSS UNIT COST, $/TON	10.40	16.40	15.62	11.00	11.20
(d) NET UNIT COST, $/TON	4.60	7.70	8.97	9.70	4.90
(e) RANGE OF UNIT COST, $/TON	3.85-6.43	6.97-12.70	6.72-10.48	8.68-9.82	2.37-7.13
(f) REFUSE CONSUMED (TONS) YEARLY	300,000	300,000	300,000	300,000	300,000
(g) RESIDUE TO BE DISPOSED		6%			7%
(h) MARKET	BAD	POOR	BAD	GOOD	GOOD
(i) ENVIRONMENTAL	POOR	POOR	POOR	GOOD	FAIR
(j) HEALTH & SAFETY	POOR	POOR	POOR	GOOD	GOOD
(k) PUBLIC ACCEPTANCE	BAD	BAD	BAD	GOOD	GOOD
(l) PLANT SITING	LIMITED	FAIR	POOR	GOOD	GOOD
(m) CONVERSION TECHNOLOGY	GOOD	GOOD	GOOD	UNCERTAIN	FAIR
(n) MAINTENANCE & REPAIR	GOOD	GOOD	GOOD	EXTENSIVE	EXTENSIVE
(p) SENSITIVITY TO PRICE CHANGE	FAIR	HIGH	NORMAL	LITTLE	HIGH
(q) CAPACITY EXPANSION	EXPANDABLE	LIMITED	MODULAR	NEED TO BUILD NEW	SOME
(r) INPUT REQUIREMENT	FLEXIBLE	FLEXIBLE	FLEXIBLE	FIXED	FIXED
(s) LABOR REQUIREMENT	UNSKILLED	SEMI-SKILLED	SEMI-SKILLED	SKILLED	SKILLED
(t) BACK-UP & STORAGE	GOOD	FAIR	FAIR	NO BACK-UP SOME STOR.	SOME

FACTORS	(6) MONSANTO PYROLYSIS	(7) UNION CARBIDE PYROLYSIS	(8) CPU-400	(9) ST. LOUIS SUPPL. FUEL	(10) VON ROLL INCINERATION	(11) ECO FUEL
(a) CAPITAL INVESTMENT	$14,862,000	11,271,000	14,000,000	6,640,000	25,200,000	70,000,000
(b) OPERATING COST, ANNUAL	3,238,000	2,271,000	2,932,000	1,856,000	3,836,000	4,000,000-4,500,000
(c) GROSS UNIT COST, $/TON	11.90	8.40	13.65	7.70	12.50	$16-18/TON
(d) NET UNIT COST, $/TON	7.30	5.50	4.18	3.80	9.70	$4-$10
(e) RANGE OF UNIT COST, $/TON	4.42-8.82	3.71-5.75	2.92-6.49	3.12-5.75	6.90-10.26	$4-$10
(f) REFUSE CONSUMED (TONS) YEARLY	300,000	300,000	328,000	260,000	350,000	250,000
(g) RESIDUE TO BE DISPOSED	7%	MINIMAL	8%	12%	18%	?
(h) MARKET	(STEAM) LIMITED	GOOD	VERY GOOD	(STEAM) VERY LTD.	(STEAM) LIMITED	GOOD
(i) ENVIRONMENTAL	GOOD	GOOD	FAIR	POOR	GOOD	GOOD
(j) HEALTH & SAFETY	GOOD	POOR	GOOD	GOOD	GOOD	GOOD
(k) PUBLIC ACCEPTANCE	GOOD	FAIR	GOOD	GOOD	FAIR	GOOD
(l) PLANT SITING	FAIR	GOOD	GOOD	VERY LTD.	LIMITED	FAIR
(m) CONVERSION TECHNOLOGY	PROMISING	PROMISING	POOR	FAIR	GOOD	GOOD
(n) MAINTENANCE & REPAIR	ROUTINE	ROUTINE	HEAVY	POOR	GOOD	GOOD
(p) SENSITIVITY TO PRICE CHANGE	FAIR	SMALL	FAIR	NORMAL	FAIR	HIGH
(q) CAPACITY EXPANSION	BUILD NEW ONES	BUILD NEW ONES	SOME	LIMITED	ROOM FOR DOUBLING	EXPANDABLE
(r) INPUT REQUIREMENT	LIMITED FLEXIBILITY	LIMITED	LIMITED	FLEXIBLE	FLEXIBLE	NOT APPL.
(s) LABOR REQUIREMENT	SKILLED	SKILLED	SKILLED	SEMI-SKILLED	SKILLED	SEMI-SKILLED
(t) BACK-UP & STORAGE	NO BACK-UP SOME STOR.	NO BACK-UP SOME STOR.	NO BACK-UP SOME STOR.	NO BACK-UP SOME STOR.	GOOD	GOOD

TABLE B-7
ASSUMPTIONS IN COST ANALYSIS
(FOR TABLES B-5 & B-6 COST ANALYSIS)

		Ranges
1.	City owns and operates the facility	
2.	1000 tpD Capacity	
3.	20 year life	
4.	8% annual cost of money	
5.	land cost: $50,000/acre	
6.	labor cost: $4.50/hr.	
7.	tin cans: $30/ton	$15 - $35
8.	Aluminum: $300/ton	$200 - $350
9.	Paper: $25/ton	$5 - $35
10.	Glass: $20/ton	$10 - $25
11.	Steam: $.50/1000 lbs.	$.40 - $1.00
12.	Energy: $.34 million BTU	$.30 - $60/$10^6$ BTU
13.	Residue disposal: $3.00/ton	
14.	Electricity: $.008/KWH	

TABLE B-8
AVAILABLE ENERGY RECOVERY PROCESSES
FROM MUNICIPAL SOLID WASTES

Supplementary Fuel Process (10% refuse)

Von Roll Incineration Process (Saugus, Mass. type)

CPU-400 Process

Union Carbide Purox Process

Monsanto Landgard Process

Garrett Process

West Virginia University Fluidized Bed Process

Aerobic Composting Process

Anaerobic Composting Process

NRG Sanitary Landfill (with methane)

MMR Biochemical Process

(2) CPU-400 process
(3) Union Carbide pyrolysis process
(4) Garrett pyrolysis process
(5) Von Roll type incineration based on overall score

Note that the rankings based on overall score in Table B-5 do not agree with the rankings which could be obtained from consideration of just net cost in dollars per ton. For example, both Garrett and Von Roll had an overall score of 0.6 with dollars per ton values of 4.90 and 9.70 respectively. The Fairfield-Hardy composting process had a relatively low net cost but ranked last in overall score because of the past history of composting in Houston.

The CPU-400 rank of second in overall score is based on desirability in all factors except technical reliability. The performance (see Chapter 3) remains a question mark due to some unsolved technical problems.

The following comments are made as suggestions to the City of Houston in using energy recovery processes in the handling of its solid-waste.

1. Use the already shredded MMR from the Resource Recovery Plant to make Supplementary Fuel for use with coal in utility power plants. Browning Ferris Industries is considering this idea (ref. B-3). More shredding equipment could be added, the process would take advantage of already existing equipment and could be expanded.

2. Use the MMR handling equipment of the Holmes Road Incinerator to load MMR into a pyrolysis unit. This would utilize existing roads, storage, building and grounds, lifting equipment, and it would take advantage of the previously arranged location of the old incinerator. This incinerator is not functional, and the City of Houston is considering dismantling it for salvage and scrap.

These two suggestions, the information in the Tables and the assumptions about the City of Houston, all seem to indicate that the St. Louis supplemental fuel concept should be considered for Houston, Texas.

The supplemental fuel concept could be gradually integrated into Houston's present solid-waste management program. The growth of its use in Houston could depend on both the growth of Houston and the user's familiarity with the concept and ability to handle the solid fuel effectively. Implementation of this idea would include engineering studies of potential user facilities, negotiations for contracts, arrangements with Resource Recovery Inc. to coordinate existing shredding equipment, and decisions concerning ownership, management and sharing of expenses between the public and private sectors.

To some extent, Houston seems to be gradually leaning in this direction. Browning Ferris Industries is considering the market potential of a solid fuel made from solid-waste.

FUTURE BENEFITS

As land becomes more expensive, as pollution and landfill regulations become stricter, and as the availability of energy becomes more important, the concept of energy recovery from solid-waste will become more profitable. Market adjustments to the concept of utilizing materials recovered from solid-waste would naturally follow improved capabilities to extract aluminum and glass, as well as ferrous metals and paper, from MMR. As the technology to extract these materials improves and the need for raw materials increases, the concept of recovering materials and energy from solid-waste will become more beneficial.

SELECTED REFERENCES

B-1 Where Innovation Harmonizes with a Boom Town Tune. Solid Waste Management, May 1974, p. 26.

B-2 Darnay, A.; and Franklin, W. E.: Salvage Markets for Materials in Solid Waste. EPA 1972, pp. 121-124.

B-3 City Joins Forces with Industry at Reconversion Center. Solid Waste Management, May 1974, p. 95.

APPENDIX C
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1974

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APPENDIX E

VENDOR LIST

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VENDOR LIST

The following are contacts for further information regarding equipment and processes mentioned in this report. The listing of a particular manufacturer does not imply endorsement. The list is not intended to be exhaustive.

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P. O. Box 6406
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Newell Manufacturing Company
726 Probandt
San Antonio, Texas 78204

Pennsylvania Crusher Corporation
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Broomall, Pennsylvania 19008

Saturn Manufacturing, Inc.
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Wilsonville, Oregon 97070

Titan Engineering, Inc.
323 South LaSalle Street
Indianapolis, Indiana 46201

Tollemache, Ltd.
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Williams Patent Crusher & Pulverizer Co.
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St. Louis, Missouri 63102

SEPARATION EQUIPMENT

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Checker Industries Corporation
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Dings Company
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Tonawanda, New York 14150

Feeder Corporation of America
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FMC Corporation
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Chicago, Illinois 60601

S. G. Frantz Company, Inc.
P. O. Box 1138
60 East Darrah Lane
Trenton, New Jersey 08606

W. W. Grinder Corporation
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Minneapolis, Minnesota 55427

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Peddie Building
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Magnetool
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Irvine, California 92705

Battelle Pacific Northwest Laboratories
Energy and Waste Section
Battelle Blvd.
Richland, Washington 99352

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Gainesville, Florida 32602

Bureau of Mines, Energy Research Center
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St. Louis, Missouri 63166

Rust Engineering Co.
P. O. Box 101
Birmingham, Alabama 35201

Torrax Systems, Inc.
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Union Carbide Corporation, Linde Division
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New York, New York 10017

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Wallace Atkins Oil Corporation
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Chemical Engineering Department
Morgantown, West Virginia

ELECTRICITY FROM REFUSE BY TURBINE MEANS

Combustion Power Company
1346 Willow Road
Menlo Park, California 94025

FUEL FROM REFUSE PROCESS

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New York, New York 10022

INCINERATION EQUIPMENT

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BIOCHEMICAL GLUCOSE PROCESS

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METHANE PRODUCTION BY ANAEROBIC DIGESTION-PROCESS

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FIBER RECOVERY EQUIPMENT

Black Clawson Company
606 Clark Street
Middletown, Ohio 45042

COMPOSTING EQUIPMENT

Fairfield Engineering Company
Marion, Ohio 58466

APPENDIX F
GLOSSARY

GLOSSARY

Aggregate -- hard, inert material of graduate fragments for mixing with cementing material to form concrete, pavement, etc.

Ash -- inert particles resulting from combustion

Bimetallic can -- a metal container with a body of one metal and at least one end of a different metal

Biodegradation -- decomposition resulting from bacterial action

Byproduct -- a useful process output which is not the primary product

Char -- a solid, carbonaceous product resulting from incomplete combustion of the original material

Clinker -- a fused, vitreous product of complete combustion

Compost -- a mixture consisting (usually) largely of decayed organic matter and used for conditioning or fertilizing land

Cullet -- scrap glass used as part of the feed material in making new glass. To be useful, it must be clean and free of metallic contaminants, color sorted, and crushed into pieces 2.54 centimeter (1 inch) or smaller

EPA -- Environmental Protection Agency

Fluidized-bed -- a bed of solid particles suspended by an upward flowing gas stream

Fly ash -- finely divided ash and other particulate matter carried up the stack or chimney of a combustion device

Fossil fuel -- any naturally occurring fuel formed by natural processes acting on organic matter over geologic periods of time, e. g. peat, coal, petroleum, natural gas

Frit -- the calcined or fused materials which are the solid output of a pyrolysis process

Front-end system -- all of the steps in handling MMR from source to the stage where it is ready for conversion processing by incineration, pyrolysis, or biodegradation. Also referred to as pre-processing or pre-conversion processing.

FWPCA -- Federal Water Pollution Control Act of 1970

Garbage -- includes all putrescible animal or vegetable waste resulting from the preparation, cooking and serving of food, or the storage and sale of produce

Groundwater table -- the level of underground water used for wells and springs

Hummus -- a dark complex, variable material resulting from partial decomposition of plant or animal matter and forming the organic part of the soil

Incineration -- the process of complete combustion

Leachate -- water which has percolated through a sanitary landfill

MMR -- Mixed Municipal Refuse

Mesh -- openings in a screen or sieve for sizing solid particles. Expressed as the size of the opening (e. g. 1/4-inch) or as the number of openings per linear inch of screen (e. g. 28-mesh).

NLC -- National League of Cities

Natural gas -- gas formed in the ground by natural processes

OSHA -- Occupational Safety and Health Administration. Also used to refer to the Occupational Safety and Health Act of 1970.

Pre-processing -- see Front-end system

Particulate matter -- finely divided particles

Pollutant -- any type of discharge which produces undesired environmental conditions

Product gas -- any gas manufactured by an artificial process

Pulp -- wood or paper fibers in a water slurry used in paper making

Pyrolysis -- destructive distillation, or thermal decomposition, process without complete combustion

Pyrolyzer -- reaction vessel in which pyrolysis takes place

PVC -- polyvinyl chloride

Recycling -- refers to separation and reuse (possibly with processing) of various components of MMR

Refuse -- includes all putrescible and

nonputrescible solid wastes, including garbage, rubbish, rubble, trash, small dead animals, ashes, tree limbs, yard clippings, grass cuttings, yard cleanings, leaves, solid commercial and industrial wastes, but not including body wastes, junk motor vehicles, special bulky wastes, dirt, or rocks

Residue -- material of little or no value remaining after a combustion, conversion, or similar process has been completed

Rubbish -- includes all nonputrescible solid wastes, consisting of both combustible and noncombustible wastes including but not limited to, paper, ashes, plastics, cardboard, tin cans, yard clippings, wood, glass, rags, discarded clothes or wearing apparel of any kind, or any other discarded object or thing, not exceeding three feet in length

Sanitary landfill -- a disposal method in which solid waste has been buried under at least 6 inches of compacted soil cover

Scrap -- manufactured articles or parts rejected or discarded and useful only as a material for reprocessing

Secondary material -- a material that is utilized in place of a primary or raw material in manufacturing a product

Sensitivity -- the extent to which one variable factor changes when a related factor is changed by one unit

Solid waste -- includes all manner of useless, unwanted, or discarded solid or semisolid domestic, commercial, industrial, institutional, construction and demolition waste materials, except human or rendering wastes

Solid waste management -- the purposeful and systematic control of the transportation, storage, separation, processing, recovery, recycling, and disposal of solid waste

Supplemental fuel -- a fuel used to supplement a primary fuel

Surface water -- water existing with its surface exposed to the atmosphere

Trade off -- sacrificing all or part of one advantage in order to gain, or increase, another advantage

Trash -- includes solid wastes such as ashes, tree limbs, yard clippings, etc., excessive amounts of paper, cans, bottles, or other household rubbish and all other things of a similar nature

Water-wall -- a wall in a combustion device made of closely spaced steel tubes welded together with water or steam circulated through the tubes to extract heat from the combustion zone

Virgin material -- a material made from unused natural resources

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